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ABSTRACT

The purpose of this study was to establish more precisely what factors determine energy use in schools, to evaluate the efficiency of and necessity for these, and to make recommendations for the reduction of energy use. These recommendations will be applied to the design of specific projects that will be built, monitored, and evaluated. This report covers the pre-design research phase. Data sources for the study include New York City schools, five suburban school systems in the New York City region, and 31 electrically heated schools in the northeastern U.S. The report concludes that with recommended new standards in lighting, ventilation, and building design and with utilization of solar energy schools can be designed to operate with no educational penalty at a savings of from 25 to 50 percent of the monitored New York City level. (Author/MLF)

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research
design
construction and
evaluation
of a

low energy utilization school

research

phase 1: interim report

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research
design
construction
and
evaluation
of a

LOW ENERGY UTILIZATION SCHOOL

Research
Phase 1: Interim Report

prepared for
Board of Education
City of New York
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ABSTRACT

Substantial energy savings can be achieved in schools. These findings, substantiated in this report, are based on a re-examination of the educational determinants that have influenced energy consumption in the past, and on a review of the technical performance of the building components. Since educational buildings represent 7 percent of the building area in total U.S. construction, these savings are considerable.

New York City has a comparatively well run system with an average use per thousand square feet of 7.32×10^7 btu's for heating and 5.27×10^7 btu's for source generation of electricity. This is only two-thirds to one-half of the fuel and electricity used in other schools whose energy records were gathered for this and other studies. Nevertheless, they also represent a spread with a standard deviation of thirty and thirty-five percent of the mean. Based on a study and analysis of these schools, the following general observations have been made:

- Delivered light in classrooms deviates substantially above and below the designed 60 footcandles with no awareness by the occupants.

- There is no correlation between higher light levels and educational achievement, according to Board of Education Standard tests. Changes in the school environment (lighting, painting, cabinets, etc.) are followed by short-term gains in educational achievement.

- There is no dangerous change in quality of air with ventilation less than one-third the present prescribed level. Tests carried out under these conditions showed a generous safety factor.

- Light delivery can be more selectively controlled in several practical ways.

- Sealed, minimum window school buildings consume considerably more energy (up to three times the average) than buildings having open window air supply possibility.

- Ventilation replacement is responsible for about two-thirds of the heating load in New York City schools.

- Solar energy can contribute to heating requirements as well as providing for domestic hot water.

In all, with recommended new standards, schools can be designed to operate with no educational penalty at savings of twenty-five to fifty percent below the already carefully monitored New York City level.

ACKNOWLEDGEMENTS

The preparation of this report has benefited from the co-operation and participation of a number of people. Their assistance and contribution is gratefully acknowledged.

First, the National Science Foundation through William Wetmore, the Director and Frederick T. Sparrow, the Deputy Director of the Office of Systems Integration and Analysis and through David Seidman and Harold Horowitz, the Project Coordinators, has encouraged us in our work by their support of this research program.

Second, the Board of Education of the City of New York has freely made available its records, its experience and the involvement of various key persons in its organization- Raymond G. Hudson, Director of the Bureau of Plant Operations; Frank McGerald of the Fuel Management Section; Bernard Lakritz, Director, Bureau of Maintenance and the principals and staff of numerous schools. Wilton Hines of the Office of Educational Facilities Planning, who served as our liaison, not only helped expedite the project, he also provided insights into the educational implications of our work. All of this was made possible through the leadership and initiative of Dr. August Gold, Administrator of the Office of Educational Facilities Planning and Hugh McLaren, Executive Director of the Division of School Building who have been deeply involved from the start in making the project successful and informative, first, as it affects the City's educational and energy programs and second, as these lessons can be applied nationally.

The National Bureau of Standards, through Frank Powell, Section Chief of Thermal Engineering Systems Section of the Building Environment Division has been a co-participant in several of the key studies and has maintained a close co-ordination of their work and ours.

The report relied on several experts for technical support. These include Dr. Ralph G. Nevins, Ventilation; Bruce Anderson, Solar Information and Karl Sklar, Control Systems.

Finally the great contribution of the research team must be noted, particularly, Ilse Reese's scholarly and literary analyses especially in the area of school lighting. The engineering expertise of Peter Flack of Flack & Kurtz was of great importance to all sections of the report. Ralph Sobel's illustrations aid considerably in the presentation of information.

We also wish to acknowledge with thanks the participation of an advisory committee who will have reviewed this interim report and have agreed to continue to assist the project in its later stages - Prof. Hermann Field, Medford, Mass.; Alan Green, New York, N.Y.; Prof. Sean Wellesley-Miller, Cambridge, Mass.; Prof. Henry Rissetto, New York, N.Y.; Dr. Edmund O. Rothschild, New York, N.Y.; Dr. Maxine Savitz, Washington, D.C.; Dr. Bernard Spring, New York, N.Y.; Edward Stephan, Chicago, Ill.

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preface

Recent events have demonstrated the importance of energy as a determining factor for major decisions in almost all segments of our society. Its unlimited availability can no longer be taken for granted regardless of the economic resources which we are prepared to commit. We can expect to operate within the framework of limited energy for the foreseeable future and whether the distribution mechanism is economic competition or some form of regulation, efficient use of this limited resource will increase the number of options which are available to us as a society. In addition, as the easily accessible fuel resources are exhausted, the search for and extraction of energy materials will have an ever-increasing effect on the natural environment.

According to the 1972 Dodge Reports, educational facilities accounted for about 14 percent of all non-residential building carried out in the United States. Two percent of this was in the New York City public school system alone. Added to the quantitative importance of school building is the social importance of these facilities and the need to insure that they will be able to continue operations in the face of possible future energy restrictions.

All of the above considerations have led to the selection of a projected school building in New York City as a prototypical study project to permit research, design and evaluation of energy saving approaches and techniques. This report covers the pre-design research phase. The overall approach has general applicability to other building types and other localities and the specific recommendations are also helpful if viewed with the understanding of the unique conditions which generated them, that is, those factors which are particular to New York City schools.

1. School locations are generally urban, implying small sites which in turn require multi-story buildings in order to achieve required floor areas.

2. The fact that the buildings are generally in densely built areas makes the man-made micro-climate particularly important.

3. The New York City school system is large, containing almost a thousand buildings. This results in vast accumulated experience and the ability to experiment with school facilities.

4. The performance of operating personnel is in part evaluated in terms of energy efficiency in buildings operation. Since this evaluation is related to job mobility within the systems, it acts as an incentive device for the efficient operation of the school plant, a result verified by carefully kept performance records.

5. When buildings are not in use, (nights, weekends and holidays) the systems are shut down. This has led to the almost universal use of steam as the heating medium because of its ability to provide rapid morning heat-up and because of the fact that the pipes are dry when the system is off which eliminates the possibility of accidental nighttime or weekend freeze-ups.

Two aspects of the report itself must also be kept in mind. First, for convenience and clarity, the aspects of energy use have been compartmentalized; however, it must be stressed that no element operates in isolation and that it is the overall performance of a building, or in some cases, group of buildings, that must be evaluated. Second, throughout the report, terms have been used which, to specialists, have very specific and somewhat limiting connotations. In most cases, the more general meaning is intended. For example, the work classroom refers to any area in which activities normally associated with the learning program take place and is largely interchangeable with the term 'learning space'. In addition, when a prototype classroom is used to show a specific example of a system, it stands for all such generalized spaces.

One final aspect of the specifics relating to this study is that both educational approaches and energy technologies are rapidly changing. In many cases where changes can be anticipated, these areas have been noted. It is, however, in the nature of change that much that is not anticipated will occur. To this end, care must be taken not to lock an approach too tightly to any single educational philosophy or environmental system and to avoid the interdependence of systems which may have very different functional life spans.

With these considerations in mind, it is hoped that this report will serve as a useful tool to others who undertake energy conservation provisions in building programs and it is to this end that the report is directed.

a

basis for the study

The purpose of the study was to establish more precisely what factors determine energy use in schools, to evaluate the efficiency of and necessity for these, and to make recommendations for the reduction of energy use. These recommendations will be applied in the next stage to the design of specific projects which will then be built, monitored and evaluated.

The New York City Board of Education manages almost a thousand of its own buildings and in addition, some rented spaces. Their operating statistics have been the basis for some general observations, detailed investigations of specific schools for others.

The Division of School Buildings operates a Fuel Management Section which monitors fuel and electricity usage on a monthly basis. This information, based on actual meter readings, serves as the basis for monthly consumption figures for New York City schools. The Fuel Management Section also prepares a yearly summary which is used for the annual figures. In addition to these recorded data, this body of buildings provided the source for the data regarding on-site conditions.

In order to provide some basis for comparison, several sources outside the New York City school district were used. These include general data received by the New York City Board of Education from four suburban school systems in the New York City region, specific monthly data taken for five suburban schools for a three year period and data for thirty-one electrically heated schools in the northeastern United States in a degree-day zone similar to New York's.

Where subjective data and evaluation were required, the report leaned heavily on the cumulative experience in school planning, design and operation contained in the

Division of School Building and Office of Educational Facilities Planning of the Board of Education.

METHODOLOGY

In conducting the research for this report, the investigators were fortunate to have the cooperation and collaboration of the New York City Board of Education, which has at its disposal detailed and long term records of about 1,000 schools. It has been possible to eschew computed simulations and to depend instead on the large fund of information contained in the school records to provide the investigators with the necessary background information for the report. The classrooms themselves were used to determine classroom performance rather than seeking to approximate conditions in isolated laboratory tests. Consequently, the propositions and findings set forth in this report are based primarily on actual data from functioning schools.

The Division of School Buildings, through its Fuel Management Section made available the records of 499 oil-fired schools and 454 coal-heated schools. The Board of Education has also provided detailed information concerning types of construction, boiler plant, ventilating systems and special ventilating requirements, lighting, fan, pump and refrigeration requirements in order to weigh the effectiveness of various building types and mechanical systems. Detailed study was based on the use of plans and specifications and inspection trips to the schools involved.

The records of The Board of Education Office of Educational Facilities Planning also furnished the basic data for studying what interrelationship existed between light levels and reading/comprehension scores of 30,000 pupils.

A number of field studies were conducted, such as the visit of a team of investigators to observe the light levels in 20 classrooms under normal conditions (sub-report g-1) and to observe ventilation performance under normal and abnormal conditions (sub-report g-2).

Under the direction of two educational experts from the Board of Education, actual school situations were observed and analyzed in order to assemble a complete list of educational tasks which could be used to determine the lighting, ventilation and temperature needs of each educational task (sub-report i).

In sum, it has been the main aim of the investigators to understand the real needs of the educational program and the true performance of the educational plant in order to know where energy saving recommendations could be made at no loss or a possible gain in the educational environment. These were based on actual conditions and actual requirements.

b

summary of findings

1● ANALYSIS OF RECORDED AND OBSERVED DATA

The following energy categories for annual energy usage, based on The Board of Education's recording methods, were evaluated:

1. Fuel oil use
2. Electricity use in oil-heated buildings
3. Coal use
4. Electricity use in coal-heated buildings

Due to the recording methods, the number of buildings in each heating category do not exactly equal the number in the corresponding electricity category. However, each section has sufficient numbers to be independently valid. For heating fuel, 499 oil-fired schools and 454 coal-fired schools were evaluated representing 56,678 msf* and 35,263 msf respectively. The electric usage in 461 oil-heated schools and 461 coal-heated schools was evaluated. These samples included 54,214 msf and 35,590 msf respectively.

Fuel Oil

The total annual fuel oil usage for the sample year was 29,641,068 gallons which averages 523/gal/msf/yr. At 140,000 btu/gal, this represents 7.32×10^7 btu/msf/yr.

Coal

The total annual coal usage was 114,632 tons, averaging 3.25 tons/msf/yr. At 14,600 btu/lb (or 2.92×10^7 btu/ton) this represents 9.49×10^7 btu/msf/yr.

Electricity

The total annual electricity usage in the oil-heated schools was 209,324,174 kwh averaging 3861 kwh/msf/yr. This represents 1.32×10^7 btu/msf/yr at the point of use (3412 btu/kwh) and 5.27×10^7 btu/msf/yr at the generator (based on Con Edison's reported heat rate of 12,400 btu/kwh and 10 percent transmission and distribution loss).

*msf (thousand square feet of gross building floor area) are used throughout the report as a unit of measure.

b/2
Summary of Findings

The total annual electricity usage in the coal-heated schools was 110,703,317 kwh averaging 3110 kwh/msf/yr. This represents 1.06×10^7 btu/msf/yr at the point of use and 4.24×10^7 btu/msf/yr at the generator.

Total Source Energy

The oil-heated schools used an average:

7.32×10^7 btu/msf/yr fuel oil
1.32×10^7 btu/msf/yr electricity
8.64×10^7 btu/msf/yr total at building

or

7.32×10^7 btu/msf/yr fuel oil
5.27×10^7 btu/msf/yr generation
12.59×10^7 btu/msf/yr total source fuel

The coal-heated schools used an average of:

9.49×10^7 btu/msf/yr coal
1.06×10^7 btu/msf/yr electricity
10.55×10^7 btu/msf/yr total at building

or

9.49×10^7 btu/msf/yr coal
4.24×10^7 btu/msf/yr generation
13.73×10^7 btu/msf/yr total source fuel.

Comparison with other School Districts

It is worth comparing these figures with data from several other sources.

1. Four suburban school districts within a 30 mile radius of New York City reported that schools ranging in size from 50-200 msf showed an annual oil usage averaging 755 gal/msf/yr compared to 523 gal/msf/yr for New York City schools.

2. Five schools (26 msf, 59 msf, 86 msf, 192 msf, and 350 msf -- a total sample of 713 msf) in a suburban school district about 20 miles from New York City (average 4800 degree days/yr for the three-year period observed), showed an average use of 828 gal/msf/yr and 5111 kwh/msf/yr as compared with 523 gal/msf/yr and 3861 kwh/msf/yr in comparable New York City schools.

3. Thirty-one all-electric schools in a zone in the Northeast United States (4501-6000 annual heating degree days) offer the following data, though direct comparison is somewhat difficult for the following reasons:

a) Records for electric schools show only energy consumption at point of use.
b) Some of the schools in the sample are air-conditioned.
c) Electric schools are generally built to NEMA standards (10 of the 31 are double-glazed for example).

b/3
Summary of Findings

The average annual electricity usage for the sample was 15,700 kwh/msf/yr. In order to make some comparison, the following assumptions were made:

a) Air-conditioning represents about 10 percent of the annual electric usage.
b) The electricity used for non-space conditioning functions will be similar for the electrically heated schools and New York City schools.

This results in a total annual use of 14,130 kwh/msf/yr without air-conditioning of which 3861 kwh/msf/yr is assumed to be for non-heating functions; 10,269 for heating. This represents 3.50×10^7 btu/msf/yr actually delivered to the space. With Con Edison's heat rate, this would require 14.01×10^7 source btu which, if provided by #6 oil, would be the equivalent of 1001 gal/msf/yr.

4. A report prepared by the Minnesota Energy Project dated 15 February 1974 cited a heating fuel consumption of 15.8×10^6 btu/yr/student and an electric consumption of 613 kwh/yr/student. This compares with 7.5×10^6 btu/yr/student and 289 kwh/yr/student in the New York City school system.

Conclusions

It is apparent that the New York City Board of Education builds and operates schools which represent the most energy efficient approaches in current design and maintenance techniques. This is due in large part to the vast experience accumulated as a result of the size of the total city educational plant. In order to ensure that non-typical conditions either positive or negative are observed and responded to, the Division of School Buildings established a Fuel Management Section which monitors all monthly energy usage of all schools. When a building uses abnormally high amounts of energy, the causes are identified and corrected if possible, and avoided in future buildings. If fuel usage is low, the energy-saving factors are introduced into existing or new schools. In addition to this central monitoring, the Bureau of Plant Operation provides a substantial training program for its custodial staff. This combination of experience and concern has resulted in practices which have served as the standards for other public agencies, some of which actually utilize the Board of Education's training program. One aspect of the second phase of this study will be to consolidate this information with additional material derived from this report. Such guidelines will have general utility in school districts where size or organization has not permitted the degree of energy efficiency of the New York City Board of Education.

Where changes are recommended, they generally result from a reassessment of the conditions in which educational tasks can occur and the tailoring of systems to respond to these revised standards, from the availability of new technolo-

gies growing out of the recent nation-wide concern for energy conservation, from the re-evaluation of certain systems which were developed and promoted at a time when national priorities were considerably different from today's, and from the realization that increases in energy costs make many options economically feasible where they were impractical only months before. In short, recommendations made regarding New York City Board of Education buildings will apply to vitually all similar buildings, and energy savings that are achieved are done so within a system which is already operating at the most efficient end of the energy use range.

Modifications for Energy Saving

Within this context the following areas were noted as being susceptible to modification for energy savings:

1. The consumption of energy varied substantially from school to school. Fuel oil use showed a mean of 519 gal/msf/yr and a standard deviation* of 154 gal/msf/yr. Electricity showed a mean of 3637 kwh/msf/yr and a standard deviation of 1403 kwh/msf/yr. (Note: mean figures are in unweighted averages). A substantial portion of this variation is due to differences in scheduling. Some portions, however, were clearly attributable to type of construction, mechanical systems, patterns of operation, etc. Those factors causing high usage can be isolated and avoided, those which conserve energy should, where possible, be incorporated in future construction.

2. Delivered environmental conditions within teaching spaces vary from building to building and within individual buildings. Little or no obvious correlation was noted between the effectiveness of the teaching and the environmental conditions with the possible exception of lethargy observed in several classrooms whose temperature was greater than 78° F.

3. Delivered environmental conditions were frequently unrelated to the specific activities which were taking place within the space. To a large degree, this is due to the lack of flexibility of the systems. The mechanical systems are designed to meet the most critical criteria which are rarely applicable. Because of the inflexibility, full output is delivered whenever any mechanical assistance, however small, is required.

4. Mechanically supplied services frequently overlap natural ones. This results from at least three causes. First, buildings in themselves are often not designed to take advantage of natural environmental conditions when available and adequate. Second, when natural delivery of desired interior conditions takes place, it is often impossible to deactivate the mechanical system providing the

* standard deviation $= \sqrt{\frac{\Sigma x^2 - 1/n(\Sigma x)^2}{n - 1}}$

same service. Third, when manual controls are provided for the deactivation of mechanical systems, they are often ignored even when it is totally unnecessary to keep the service in operation.

5. Mechanically supplied services were frequently provided in unoccupied areas. In some cases this was due to the inability of the systems to be locally deactivated. In others, it was caused by the unwillingness of the staff to take advantage of the available controls.

6. Services were often delivered at a level much higher than desired. This appeared to be due to failures in the control systems resulting from either normal malfunction, vandalism, improper calibration or inadequate maintenance.

7. In general, the more complicated sophisticated systems functioned far less effectively than the simpler, more common ones. Buildings that relied entirely on mechanical delivery systems for their interior conditions appeared to have the greatest number of problems with control systems, to have the widest temperature variations and to consume the most fuel.

Potential Savings

Current energy usage in school buildings is as follows:

<u>Total Fuel Oil Use</u>
7.32×10^7 btu/msf/yr

which breaks down approximately into

(A) Domestic Hot Water	$.72 \times 10^7$ btu/msf/yr
(B) Heating due to introduction of outside air	4.40×10^7 btu/msf/yr
(C) Heating due to conducted loss	2.20×10^7 btu/msf/yr

<u>Total Source Energy for Electrical Generation</u>
5.27×10^7 btu/msf/yr

which breaks down approximately into

(D) Lighting	3.16 btu/msf/yr
(E) Fans	1.32 btu/msf/yr
(F) Other	0.79 btu/msf/yr

These quantities are represented by figure b/2.

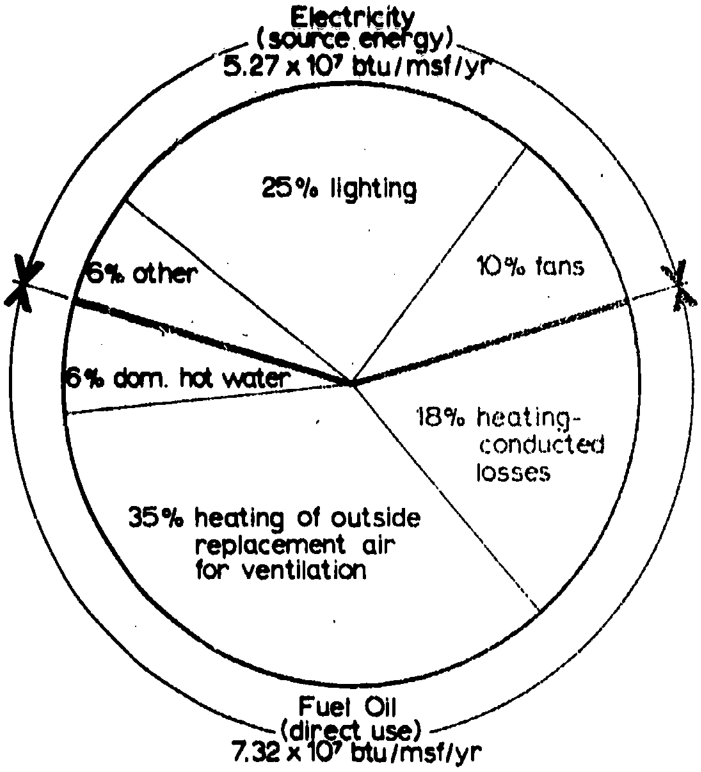
It is anticipated that the following savings can be achieved through the recommendations included in this report (figure b/1).

FIGURE b/1: CURRENT ENERGY USE IN SCHOOL BUILDINGS AND ANTICIPATED SAVINGS

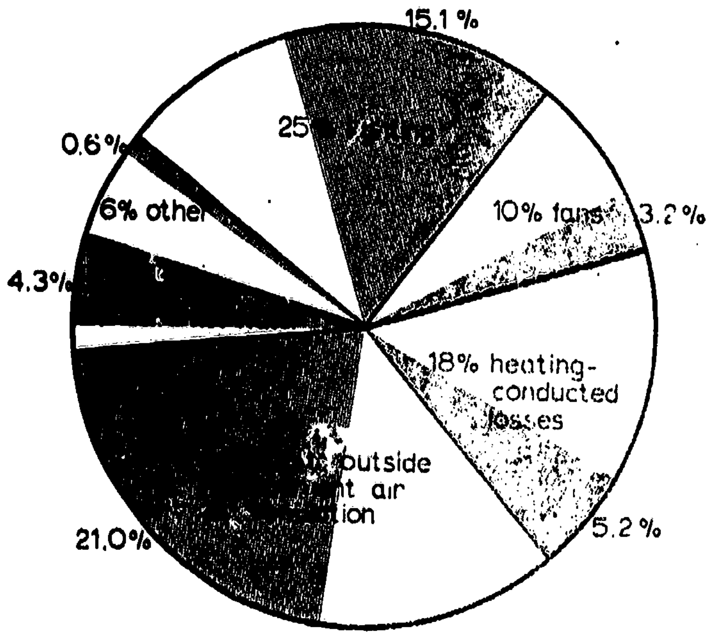
Major Energy Uses	CURRENT btu/msf/yr (x 10^7)	CURRENT percent of total	NEW BUILDING saving percent of (2)	NEW BUILDING btu/msf/yr (x 10^7) saved	NEW BUILDING percent of total saved	RETROFIT saving percent of (2)	RETROFIT btu/msf/yr (x 10^7) saved	RETROFIT percent of total saved
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A) Domestic Hot Water	.72	6	75	0.54	4.3	50	0.36	2.9
B) Htg. Ventilation	4.40	35	60	2.64	21.0	30	1.32	10.5
C) Htg. Conduction	2.20	18	30	0.66	5.2	15	0.33	2.6
D) Lighting	3.16	25	60	1.90	15.1	40	1.26	10.0
E) Fans	1.32	10	30	0.40	3.2	20	0.13	1.0
F) Other	0.79	6	10	0.08	0.6	10	0.08	.6
Total	12.59			6.22	49.4		3.49	27.7

b/7
Summary of
Findings

Present Energy
Use Pattern



Projected Savings
(New Building)
49.4% total
Note: Shaded areas
represent anticipa-
ted savings.



Projected Savings
(Retrofit)
27.7% total

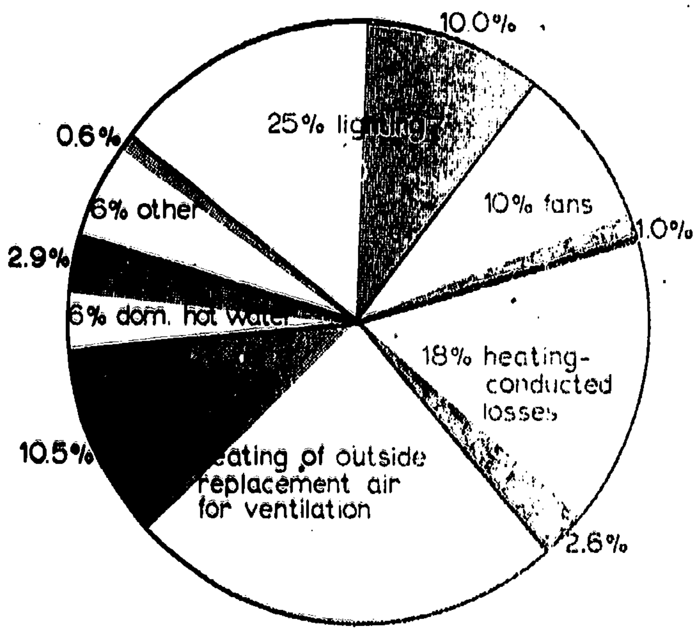


FIGURE b/2:
CURRENT ENERGY
USE IN SCHOOL
BUILDINGS AND
ANTICIPATED
SAVINGS

RECOMMENDATIONS FOR SYSTEMS AND STANDARDS

The following recommendations for systems and standards have been extracted from prototypical proposals (section d) and school usage patterns (sub-reports g, h and i).

Building Configuration

1. Evaluate program to determine areas that can take greatest advantage of natural light and ventilation.

2. Arrange building so that those spaces which can benefit from natural light and natural ventilation are located at the perimeter of the structure. In this way unavoidable, unwanted heat loss and gain will be offset by natural means of satisfying light and air requirements.

3. Arrange building so that spaces which can least benefit from natural light and ventilation are located in the interior portions of the building.

4. Orientation will be governed by site restrictions. If options are available, orientation will be determined by solar consideration, according to criteria which will maximize solar heat gain in the peak heating season (particularly in the early morning to reduce start-up loads) and minimize heat gain in temperate and hot seasons. The wind patterns in most urban sites are erratic precluding orientation based on prevailing air currents; however, in cases where buildings are in highly exposed sites, this must be considered.

Building Skin

1. Desirable characteristics of the building envelope are a high resistance to unwanted thermal transfer and an ability to utilize natural light, ventilation and solar heat when available and desired.

2. Provide an average roof U-factor of 0.06.

3. Provide an average wall U-factor of 0.15. 0.15 is the average of all wall, window and door surfaces based on the use of thermal shutters as follows:

Opaque Wall	64% x U @ 0.06 =	0.0384
Windows (thermal shutters closed)	35% x U @ 0.30 =	0.1050
Doors	1% x U @ 0.60 =	0.0060
	TOTAL	0.1494
	SAY:	0.15

Opaque Wall	64% x U @ 0.06 =	0.0384
Windows (thermal shutters open)	35% x U @ 1.13 =	0.3955
Doors	1% x U @ 0.60 =	0.0060
	TOTAL	0.4399
	SAY:	0.44

Note: These factors are for walls with thermal shutters <u>only</u>. Overall wall thermal performance to result in average U-factor of 0.32 without requiring shutters.

4. Provide windows to permit natural lighting to be utilized for ambient lighting throughout ten-foot deep perimeter zone.

5. Provide insulated shutters at windows to prevent excessive heat loss when the light transmitting properties of the glass are not required.

6. Provide solar shading to prevent excessive heat gain when it is not desired.

7. Provide an average U-factor of 0.14 for slabs between heated and unheated spaces.

8. Provide slab on grade with vertical edge insulation with total average U-factor of 0.12.

Thermal Mass

1. The selection of structural, closure and partitioning systems will have an effect on thermal mass which is independent of thermal transmission characteristics.

2. High thermal mass building will perform with less fuel use when outside temperatures swing above and below acceptable inside temperatures (summer). Low thermal mass building will perform better when outside temperatures remain consistently above or below acceptable inside temperatures (winter). In selecting one or the other, trade-offs between the seasonal differences must be weighed.

3. The choice of high or low thermal mass construction will have to be evaluated at the time of actual building design, using a computer simulation reflecting actual scheduling, program, site, etc.

Solar Energy

1. Provide a flat plate water solar collector supplying a heat exchanger to preheat domestic hot water. Careful metering of this system will provide data to permit more accurate evaluation of solar energy systems in the New York City area.

2. Provide passive thermo-siphoning wall panels (may be installed selectively for comparison and evaluation) for heating as described in 'Building Skin' (section d-3).

Lighting

Classrooms

1. Provide approximately 40 percent of the classrooms with increased switch circuiting to permit both localization of light delivery and modulation of level by "checkerboard" light patterns.

2. Provide approximately 40 percent of the classrooms with multi-level fixtures to permit reducing light levels throughout entire classroom to those actually required for activities taking place.

3. Provide each of the remaining classrooms with either a conventional track-light system, a system of fixed lights with adjustable switching patterns or a system where both fixtures and switching are adjustable, the last two being accomplished either by multi-wire low voltage or multiplexed control systems. In addition, provide some of these rooms with automated switching on an experimental basis. This might include photo-sensitive controls for perimeter zones and timed shutdown of lights based on end of period signals.

4. Provide selected rooms with a series of work stations with integral lighting to permit a low general light level to be maintained while still satisfying requirements for those students performing demanding visual tasks.

Special Purpose Rooms (Gymnasium, Cafeteria, Auditorium, etc.)

1. Re-evaluate the scheduling and use patterns expected in each area of the specific building in question and provide appropriate light delivery system with particular emphasis on ability to deactivate areas or reduce levels when services are not needed. For example, in keeping with current use practices, provide two light environments in an auditorium -- one for assembly, one for study hall use. In a cafeteria provide lighting conditions suitable for dining, maintenance and study hall use. Controls should permit selective lighting of individual areas within cafeteria for times when groups are using small portions of the space.

2. Provide automated shut-down of light systems when it is anticipated that occupants will not utilize systems and when scheduling can be easily predicted.

Offices

1. Provide ambient light levels of 15-20 footcandles and specific illumination at work stations. Note: the ambient light may be provided by the same fixtures which provide the task light permitting great flexibility in the space use.

Corridors

1. Provide light levels of 5-10 footcandles in corridors.

2. Use light-reflective wall surfaces.

3. Where alcoves or short corridors occur, provide supplementary illumination to prevent shadowed pockets.

Future Modifications

Note: Provide service capacity for possible future augmentation of lighting systems to current standards.

Heating

Standards

1. Outside design temperature 5° F

2. Classroom design temperature 68° F (set at 65° F)

3. Administrative area design temperature 68° F

4. Gymnasium design temperature 65° F and 70° F based on type of activities taking place

5. Storage area design temperature 50° F

6. Other spaces as called for in latest School Design Planning Manual

7. Exposure factors to be determined after site selection

Distribution System (predicated on heating only with no provision for additional air-conditioning)

1. Utilize low pressure steam with vacuum return.

2. Sectionalize building and system to permit selective heating of spaces including small groups of classrooms, auditorium, and gymnasium during after-school hours.

3. Use dual level thermostats (similar to day/night thermostat using automatic reset with override feature) to allow two levels of settings and system off.

4. Locate controls centrally to facilitate the selective use of the system.

Boiler

1. Except as noted below, #6 oil is recommended. Provide a minimum of three boilers, two of which will be sized at 40 percent design load, the third at 20 percent.

2. If design heating load is less than 5,000,000 btuh, individually-fired multiple cast iron heat exchangers (modular boilers) in units of 10-20 percent of design load utilizing #2 and #4 oil should be considered.

Oil Burning Equipment

1. Forced draft rotary cup type burners are recommended for all grades of fuel oil except as noted below.

2. If #2 and #4 oil is to be used with modular boilers, consider air atomization medium pressure type burners.

b/11

Note: Conventional practice with rotary cup burners is to use variable dampers to modulate combustion air intake at partial operating levels. At lower levels this system is difficult to control accurately. Investigate whether a burner with a finite number of settings (e.g. four) with corresponding adjustable combustion air ports would perform better at lower fuel rates. The installation would require tuning after installation to set the fixed openings.

3. It is recommended that as part of Phase II, National Bureau of Standards evaluate a device such as the Cottell system which introduces water into the fuel-oil by ultrasonic or other means.

Terminals

1. Typical classrooms: Provide perimeter radiation with individual room control. In selected classrooms, locate temperature sensors in exhaust air ducts and place controls in secure location (possibly behind grille). This will tend to prevent tampering and false readings resulting from local conditions.

2. Kindergarten and pre-kindergarten classrooms (where programmed): Consider air floor radiant slab with hot air discharge at perimeter wall to counter cold-wall effects.

3. Gymnasium, Auditorium: Provide heated air system with 100 percent recirculation capability for warm-up and use with limited occupancy. Where more than 25 percent of the air is exhausted, analyze heat recovery devices. These may be heat exchanger wheels, air to water to air loops or air to air counter-flow exchangers.

Cooling

Note: The term cooling refers to any process which is used to lower the temperature in a space and includes mechanical refrigeration for space conditioning.

Outside air

Rooms without provision for chilled air or water will rely primarily on the introduction of outside air to prevent interior temperatures from rising due to local heat sources such as lights or occupants. This air introduction is to be considered separately from that required for basic metabolic functions which will be discussed under Ventilation. The outside air for cooling can be supplied either mechanically or by air pressure differentials or convection. Wherever possible, utilize non-mechanical means (open windows) to ensure adequate cooling air. Where mechanical means are required, the system is to be isolated from the base ventilating system either physically or by its control system. This is to ensure that regardless of air quantities introduced for temperature control, sufficient outside air will be supplied for metabolic needs.

Evaporative cooling

Provide additional comfort at elevated temperatures by ensuring air movement which results in surface evaporation at the skin. This can be accomplished using oscillating fans, ceiling fans, low speed wall fans, or it can be accomplished by the exhaust system. (Air movement does not require air removal.)

Mechanical Refrigeration

Provide chilled air to portions of the building.

1. Design Standards*
Outdoor - 88° F D.B. 75° F WB
Indoor - 78° F D.B. 60% RH

2. Chillers are to be selected based on energy sources available and demand for heat removal.

3. Primary distribution is to be chilled water.

4. It is recommended that smaller rooms (offices, classrooms, etc.) be heated and cooled with fan coil units of adequate size and number, individually controlled. In this way, the cooling function can be maintained separate from the metabolic outside air requirements.

5. Larger rooms (auditorium, gymnasium, etc.) utilize chilled air from the local air handling unit.

6. With reduced exhaust requirement, no heat recovery is anticipated related to localized chilled water systems. Large, chilled air systems may utilize the same heat recovery systems used for heating.

7. If centralized air distribution is to be used, use variable air volume systems. Avoid terminal reheat systems.

Ventilating

1. Ventilating will refer to that outside air required for healthy maintenance of metabolic functions.

2. The basic ventilation rates for areas other than those listed below will be 5 cubic feet per minute (cfm) per occupant, when space is occupied. This is based on:

a. Study performed by the National Bureau of Standards in conjunction with this report.

b. Dr. Ralph Nevins' report included as an appendix to this report.

c. Latest ASHRAE recommendation.

*based on <u>ASHRAE Handbook of Fundamentals</u>, 1972
Ch. 33 Table 1, 5% data; NYC Central Park

3. The following spaces should be provided with a ventilation rate greater than 5 cfm/occupant

a. Gymnasium - 15 cfm/participant
5 cfm/spectator

b. Cafeteria - 15 cfm/occupant
Note: Where cafeteria is to be used as an instructional space, a two-level system is to be provided which can supply 5 or 15 cfm/occupant depending on usage.

c. Special use areas such as labs, shops, kitchen which have equipment which exhaust air directly shall have appropriate make-up outside air.

4. Controls - Ventilating systems will be zoned to be coterminous with heating system zones so that after-school uses can be carried out with the least introduction of outside air by operating the fewest number of zones required. This will affect both fuel-oil and electricity usage. In addition, it is recommended that several of the classrooms with automated lighting be fitted with automated dampers integrated into the control system which would close at the end of each period and open only if the room was in use as indicated by the activation of any device in the room. In this way, any time a classroom remained empty for a period, the heating load would be reduced by the amount normally required to heat that incoming air. The fan serving those damper-controlled areas will be variable speed controlled by SCR devices such as Triacs (section d-11) responsive to the damper position.

Domestic Hot Water

1. Provide a separate hot water heater with a burner sized to meet the anticipated demand at times when there is no demand for the prime space heating boilers.

2. Deliver hot water at 100° F except for dish washing.

3. Utilize low temperature "waste" heat to preheat domestic hot water.

4. Utilize solar collector as described in earlier section.

C

educational activities and energy use

RELATIONSHIP BETWEEN NATURAL AND MECHANICAL SOLUTIONS

One of the obvious truths emerging from the observations of numerous New York City schools and the detailed analysis carried out in the preparation of this report is that energy expended in the process of conducting educational activities is actually a very small part of the total energy expenditure of a school. Effective teaching has been carried out under the most simple and unassuming conditions. Socrates taught his pupils in the shade of a tree. The early settlers in this country taught effectively in the one room schoolhouse. Today, the most valuable teaching may be carried out as effectively in the older structures as in the most recently constructed schools. In the end it is the inspiring teacher who has the greatest effect on pedagogical results.

This does not imply however, that provision of a safe and healthful environment can be overlooked in architectural design. Adequate light for safety and good vision, sensible temperature and air circulation must be provided. The purpose of this report is to find ways of effecting these desirable environmental conditions with the least amount of energy expenditure and in the least complicated way.

Technical and scientific developments have dominated and determined the total built environment in the past several decades to such a degree that we have lost sight of the natural means of controlling the environment. Unquestionably mechanical solutions are necessary where natural means are not practicable or adequate, especially in urban schools located in highly built-up areas. Nevertheless, the findings of this report indicate that natural means of controlling light, temperature and ventilation have not been used to their full potential. Mechanical systems have tended to dominate architectural design, have redundantly duplicated available natural conditions and have become overly complicated.

Natural Illumination

Natural lighting can be considered the basic light for the classroom. It has a rounded color spectrum, its variations

in intensity are within the large adjustment capabilities of the human eye, and it has immediately understood connotations linking the classroom to the outside world. Artificial illumination will serve to supplement this source (1) when insufficient natural light exists; (2) when special emphasis is needed; (3) for specific tasks; (4) for precise control of light levels. In other words, it is essential to provide a lighting system -- both natural and artificial -- which is responsive to the many varied educational activities taking place within a school. In contrast to the uniformly high light levels prescribed by various government agencies and other organizations (sub-report h-2) designed to accomodate the most difficult task at any point in the learning space, the light delivery system should be sufficiently versatile and rearrangeable so that major changes in lighting patterns can be easily accomplished. Daylight will have to be modulated by shading devices, by light baffles, by careful considerations of sizes and locations of windows (section d-5).

Artificial Illumination

Artificial illumination can be controlled by selective switching (section d-11) whereby a chalkboard can get additional artificial illumination to help attract pupil attention; to compensate for brightening or waning daylight, or to adjust to a quick rearrangement of furniture within a classroom. No longer is the accustomed classroom of 30-40 fixed seats facing the chalkboard the universal teaching space. As observed in the course of many school visits and documented in the section on Educational Activities and Desirable Environmental Conditions (sub-report i) many activities take place during each class period, and the number of students and teaching personnel are equally variable. There are no typical teaching situations: students work singly, in small groups, in class-sized groups, in assembly-sized groups performing any number of educational activities in any number of furniture arrangements. This requires a wide variety of light levels ranging from low ambient light for discussions, lectures and AV productions, to higher light levels for such tasks as reading, writing and even more demanding visual tasks such as drafting, sewing and laboratory work.

Light Levels for Schools

The actual determination of light levels has been under considerable debate over the past few decades. Recommendations for school lighting have been startlingly divergent during this time period. School light levels have risen at regular intervals based largely on the findings of controlled experiments carried out under laboratory conditions purporting to simulate actual conditions.

In considering school lighting we have viewed the classroom as the most important laboratory and have made some investigations of the conditions within classrooms and the results attained in the classrooms educationally. Our findings tend to support the point of view expressed in general terms by the British Department of Education and

Science, which based its recommendations on the work of the Building Research Station, and by Miles A. Tinker, who conducted his classroom experiments at the University of Minnesota (sub-report h-1). The experience in England and the studies of Tinker suggest that an ambient light level of about 20 footcandles is quite adequate for all seeing tasks in classrooms for children with normal vision. In classrooms for children with impaired vision, 50 footcandles are indicated. These levels should be supplemented as noted in the charts covering "Educational Tasks and Environmental Conditions" (sub-report i).

In rooms with natural light through windows on one side, measurements have established that even on an overcast day, a window with a head of 9 ft, even with shades partially drawn, provides an acceptable level of light 15 ft into the room. This implies that daylighting can fill a substantial portion of the school lighting requirements and that artificial lighting can play the supplemental role.

Comfort Levels for Schools

Similar conclusions have been drawn in the area of ventilation, heating and cooling. As pointed out by Dr. Ralph G. Nevins (sub-report g-2) under most conditions, open windows will provide more outside air than is currently specified under existing standards for mechanical ventilation. The introduction of outside air above the basic requirements should rely primarily on non-mechanical means. Mechanical support should be used only when the natural systems are inadequate.

Control Options

In conclusion, it is our contention that, with understanding, people enjoy the exercise of options that affect their comfort conditions. They prefer to participate and modify air flow, temperature and light conditions. We would no more think of questioning a person's ability to open and close a window at home, to switch a light on or off than we would question the ability to unlock the front door.

The recent reports of the experiences in industrial plants, SAAB, VOLVO, IBM in Britain and others, demonstrated that productivity, too, benefits from the greater participation of the individuals in the secondary decision-making process. Similarly, the educational achievements ought to benefit when the participants, teachers and pupils, can influence the kind of setting they are in.

d-1

prototypical proposals

1● BASIC APPROACH

The function of a building is to provide an environment in which a number of activities and tasks can be performed in safety, in health and in physical and psychological comfort. Criteria to provide these conditions frequently require that the environment created be differentiated from the natural (outside) environment. This in turn requires a barrier between the two environments (the building skin). As the restrictive properties of the barrier increase it becomes necessary to reintroduce environmental factors to the inside environment even though these services may be abundantly present on the outer side of the skin. For example, in a building with an opaque skin (no glass) it is necessary to provide internal lighting, although there is substantial daylight on the outside of that skin. In addition, as the distance from the skin increases, the availability of these "natural" environmental factors decreases.

These environmental factors are achieved for the most part through the use of various forms of energy. The direction of flow of this energy will, if not mechanically altered, be from conditions of higher state to those of lower state. At times this flow will move the interior environmental conditions away from the desired state rather than towards it. For example, when heating of a space is required, and outside temperatures are lower than inside, the natural direction of energy flow will increase the demand for heat.

Positive and Negative Energy Flow

In order to quantify and evaluate both mechanical and non-mechanical building systems in terms of their impact on overall fuel consumption, the following convention will be used to describe energy passing through the skin of a building:

a) Positive energy flow: Any non-mechanical transmission of energy through a building skin which would otherwise have to be mechanically supplied will be positive, the value being equal to the source energy required by the mechanical process.

b) Negative energy flow: Any transmission of energy through the skin of a building which results in the need to operate a mechanical system to counter the effect of the transmission will be negative, the value being equal to the source energy required by the mechanical process.

The sign of the flow is not exclusively determined by the direction of flow. For example:

a) Positive energy flow from inside to outside: Building has interior heat above desired limits. Utilizing natural air movement, heat energy is convected to outside eliminating the need for mechanical cooling.

b) Negative energy flow from inside to outside: In cold weather, building tends to conduct heat to the outside requiring a mechanical heating system to maintain minimum interior temperature.

c) Positive energy flow from outside to inside: In situation cited in (b) above, solar radiation entering the building will reduce the need for the mechanical heating system.

d) Negative energy flow from outside to inside: When over-heating is a problem, the same solar radiation will be negative, requiring some mechanical means to remove excess heat.

In terms of conserving source fuel, positive energy flow will always be desirable, negative always undesirable; so by comparing net annual positive energy flow, the relative energy efficiency of skin and system combination can be determined.

General Observations

Over the past thirty years, devices and systems which modify the internal environment have tended to be mechanical, requiring the input of energy for their operation. In designing these systems, the negative energy flow through building skin is calculated since it is this that the mechanical system must offset; however, the positive flow is usually ignored since this generally does not affect the most extreme condition tha a system will encounter. This attitude has led to a general point of view which considers building skin (or perimeter) a necessary evil which should be minimized. In this situation, every attempt is made to neutralize the energy flow between the inside and outside environments thereby creating a relatively predictable interior situation and to provide the environmental factors by mechanical means with reductions in fuel usage resulting primarily from the optimization of systems and the minimization of negative energy flow through the skin. This approach results in buildings which are totally dependent on their mechanical systems.

d-1/3
Basic Approach

By considering net energy flow through the building skin and maximizing the net positive result, a situation can be developed where mechanical systems are used only when the demands for energy consuming environmental services are greater than the positive flow can deliver. This approach requires that the building skin responds either actively or passively to the outside environmental conditions, and to the inside environmental demands. It also requires a mechanical system that can interact with conditions delivered by means other than itself. This approach is based on a combination of building skin and mechanical systems in which the greatest possible net positive energy flow through the skin results in minimizing total fuel usage. The actual efficiency of each system in operation may in fact be lower than similar alternative systems which function under more predictable conditions. Nevertheless, the fact that they do not have to function as much of the time results in overall fuel economy.

A number of factors suggest that this second approach is worth pursuing in designing a new Low Energy Utilization School:

1. Statistics indicate that buildings which rely entirely on mechanical and electrical systems for environmental control use considerably more fuel in their operation than do those which use natural means supplemented with back-up systems.

2. Observations indicate that buildings which rely entirely on mechanical and electrical systems for environmental control perform no better, and in some cases less well in providing pre-specified environmental conditions.

3. Increases in complexity of systems with predetermined interrelated responses increase potential malfunctions at a rate determined not only by the increased number of components, but also by the increased relationships between components.

4. Systems which attempt to provide environmental conditions by utilizing predetermined responses to preselected sets of conditions which are mechanically (or electronically) received and interpreted tend to minimize the ability to respond to actual human requirements unless responsiveness to local, manual input is provided.

5. Buildings which rely entirely on mechanical and electrical systems to produce acceptable environmental conditions are totally vulnerable to drastic curtailments of fuel and electricity. Buildings which use these systems as augmentation for naturally delivered factors are less susceptable to these pressures.

6. The changes and unpredictability of naturally delivered environmental services provide variation in the

educational spaces which is valuable, both in the alleviation of environmental boredom, and as a teaching factor which helps make students aware of the interrelationship of their own micro-environments and the natural environment as a whole.

7. The need to modify mechanical systems' operations as outside conditions vary is an important educational factor in familiarizing students with the procedures of operating systems in apartments, homes, work situations, etc. which they will encounter outside the school situation. Similarly, the ability to vary conditions by non-mechanical means such as opening windows or drawing shades and blinds instructs in the simple manipulation of environmental conditions.

Therefore, this report advocates the approach of producing a building in which environmental conditions are provided by factors taken non-mechanically from the adjacent natural environment whenever possible and mechanical systems when not.

Future Modifications

The new building will serve as a laboratory for the evaluation of energy saving techniques. It is possible that some of the systems will require additional back-up at some future time. With this in mind, systems where this may occur are to be designed so that this augmentation can be achieved with minimum disruption of the building.

d-2

prototypical proposals

2 ● BUILDING CONFIGURATION

a) Maximize perimeter area which reduces overall fuel consumption by using solar and wind energy.

b) Minimize perimeter area which increases overall fuel consumption due to excessive unwanted heat transfer to and from the outside.

c) Organize internal arrangement of building to use natural and mechanical environmental systems most efficiently.

Distance of occupied spaces from exterior surfaces

Any environmental factor, mechanical or natural, will be effective for only a limited distance from its point of introduction. The distance between interior areas and exterior surfaces will greatly affect the usefulness of the available natural environmental elements. These will be effective for only a limited distance from the point of introduction unless specific means are employed to extend their range. Natural light, for example, loses effectiveness as the distance from the perimeter increases (the exact loss pattern depending on the nature of the source). Hot air will tend to stratify at the upper portions of a space unless something forces it down.

As a result, if natural environmental factors are to be used in the most direct fashion, it will be necessary to limit the distance from exterior surfaces of all spaces thus served. These limitations will have to be determined for specific areas and orientations.

The above factors suggest several considerations in building configuration. Some of these may interfere with each other or may be mutually exclusive. Rather than making decisions on a component by component basis, the final set of options selected will result from overall performance analysis. These decisions must be made within the context of a specific building project.

Orientation

1. Orientation must recognize micro-environment, i.e., adjacent buildings (existing or projected), terrain, etc.
2. Building should be oriented to maximize exposure to solar radiation during the heating season.
3. Solar gain for heating should be scheduled to account for temperature lag due to thermal mass of building.
4. Relationship of building to outdoor spaces should be set to maximize positive solar impact on these spaces, i.e., snow melting, heating in winter, sunning in spring and fall, etc.
5. Relationship of building to outdoor spaces should maximize, within limits, air movement in hot weather, minimize air movement in cold weather.
6. Orientation should permit greatest utilization of outside air movement to facilitate natural ventilation.

Perimeter Area

Maximize productive exterior surface. Whenever exterior surfaces can yield positive energy flows, they are, by definition, serving to reduce source fuel use requirements as compared with a space which has no interaction with the outside environment. The evaluation of what constitutes productive surface will vary from one situation to another, depending on the actual needs of the space, the type of building skin, the orientation of the surfaces among other factors. In general, it can be said that the highest productivity from a wall survace will result from a skin which (1) can permit greatest energy flow when natural flow is in a positive direction, (2) can be most highly restrictive when energy flow is in a negative direction, (3) can permit the flow of one type of energy when that type is positive while restricting another type when that other type is negative. When these three criteria can be met and adequate natural energies (wind, solar heat and light) are available, a productive exterior surface can be achieved. In these situations, the exterior surface should be maximized. This has obvious impact on building configuration.

Minimize counter-productive exterior surfaces, that is, surface areas which, due to negative energy flow, result in the utilization of more source fuel than would be used if the surfaces had no energy transfer to or from the exterior.

There are three ways of minimizing counter-productive surfaces. One is by redesigning the skins which make up these surfaces so that they become productive. In doing this, it is important to ensure that there is a demand for the positive energy being delivered if actual source fuel savings are to be realized. For example, the natural light provided in a rarely used but constantly heated storeroom

represents a source fuel saving only if the fuel required to artificially deliver light for certain hours per day is more than the fuel required to replace heat lost by conduction through the glass. In actuality, when light is needed only a small part of the time, it is usually more economical to use artificial light which can be switched off when not needed. Where actual operating conditions do not coincide with assumed computed conditions, results may occur which are opposite from those anticipated.

The second way of reducing counter-productive surfaces is to structure the internal organization of the building to place those functions which will have the greatest demand for positive energy flow adjacent to the exterior skin.

The third method for reducing counter-productive surfaces is to actually reduce the amount of exterior skin when that skin must result in a negative flow either because of orientation, building program, micro-climate or other specific restrictions. The asymmetry of solar incidence, prevailing winds, program, etc. may lead to a situation where it is desirable to have more actual surface on one side of a building than on another.

Proportion

In order that positive energy flow be non-mechanically delivered to areas which have sufficient demand, these areas must, in general, be in close proximity to the building skin. This requires relatively thin plans and sections.

In general, building configuration will be determined by first evaluating the available demand for energy related services, the availability of natural sources of these services, the density of these sources and the efficiency with which these sources can be captured and retained. This will indicate the amount of productive exterior surface required to deliver these natural services. This is, of course, a highly idealized and abstracted situation. In the case of an actual building, a series of trade-offs will have to be weighed. There will always be some unavoidable counter-productive surfaces which will, in fact, tend to be increased by the effort to increase productive surfaces. There will be cases where the natural amount of surface area generated by a specific plan requirement will be less than that required to satisfy energy demand even under ideal conditions.

However, the synthesis of a specific building responding to the basic considerations above will yield a total entity which will be less dependent on mechanical systems to modify interior environments to acceptable standards due to an increased ability to use natural sources. If provisions are also made to restrict negative energy flow, the net result will be a decrease in the use of source fuel.

Summary of Findings

1. Evaluate program to determine areas that can take greatest advantage of natural light and ventilation.

2. Arrange building so that those spaces which can benefit from natural light and natural ventilation are located at the perimeter of the structure. In this way unavoidable, unwanted heat loss and gain will be offset by natural means of satisfying light and air requirements.

3. Arrange building so that spaces which can least benefit from natural light and ventilation are located in the interior portions of the building.

4. Orientation will be governed by site restrictions. If options are available, orientation will be determined by solar consideration, according to criteria which will maximize solar heat gain in the peak heating season (particularly in the early morning to reduce start-up loads) and minimize heat gain in temperate and hot seasons. The wind patterns in most urban sites are erratic precluding orientation based on prevailing air currents; however, in cases where buildings are in highly exposed sites, this must be considered.

d-3

prototypical proposals

3 ● BUILDING SKIN

a) Maximize positive energy flow through building skin.

b) Minimize negative energy flow through building skin. (for discussion of positive and negative energy flow, see section d-1)

The building skin, the facade, is the most visible part of the building, and is the most expressive of the whole design approach. While it has had the historic role of allowing light and air into the interior of the building when required, keeping in desirable heat and keeping out unwanted heat, in recent years it has been drastically simplified to accommodate techniques of construction and its performance requirements have been minimized, since mechanical systems were considered totally capable of providing a satisfactory interior environment. A fundamental re-examination of the requirements and performance of building skins promises to allow major reductions in energy demands.

In the complete pattern of energy use in a typical New York City school, the building skin is responsible for about 35 percent of the heat required to maintain prescribed conditions. This figure can be reduced by improving the thermal characteristics of both the glazed and opaque sections of the skin (including the roof).

Current regional practice has been to provide an overall U-factor (including glass) of about .44. By adding insulation in a cavity masonry wall, by increasing insulation in a curtain wall from 2" to 4" and by adding insulation between a masonry wall and the interior finish the U-factor in opaque walls can be improved to .1. By going from single glazing to double glazing, the U-factor of the glazed areas can be improved from 1.13 to 0.67.

These changes would improve the overall U-factor to about

.22. Based on present New York City school consumption figures, this would save about 90 gallons of fuel oil per msf of school area per year.

By introducing daylight through the building skin, interior light requirements in classrooms can be reduced by about 25 percent. For every lineal foot of glazed window in the facade, there is an annual saving of 18 kwh.

By having operable windows, the amount of electricity used to operate fans and air-conditioning can be reduced by 30 percent. This constitutes a saving of 290 kwh/msf/yr.

These are savings that can be achieved by improving the performance of the standard wall components. They are not additive, but do offer important savings.

By re-examining the performance and requirements for the entire wall, however, additional energy savings can be expected, with a wall that is more responsive to solar input when heat is required and with a greater capability of screening out solar gain when it is undesirable.

Energy Transmission and Resistance

The utilization of a large surface between inside and outside in order to reduce source energy utilization requires that the membrane that defines this surface be able to both transmit and restrict a number of different forms of energy flow depending on the availability of the various sources in the natural environment and the demand for these services at the building interior. In general, transmission is easier to achieve than resistance for conducted and convected energy transfer. Transmission is much more difficult in the case of radiated energy. If the building skin is to respond to varying situations it must, as stated above, modify these energy flow characteristics.

Positive Energy Flow

Positive energy flow, that is, energy flow that reduces the need for the consumption of source fuel can be either energy input to or output from the interior environment.

Input

Positive energy flow as input occurs in the following forms:

1. Solar radiation used as light

2. Solar radiation used as space heat

3. Conducted and convected heat when outside ambient temperature is higher than inside and inside is below desired level.

Output

Positive energy flow as output occurs in the form of conducted and convected heat when interior temperature is higher than exterior and inside is above the desired level.

Heat transfer through a building skin by conduction and

convection is not necessarily a straight line flow but can be around corners, curves, etc. requiring only that there be a driving pressure to induce the energy or medium to move. In the case of conduction, this would be a temperature differential. In the case of air convection, it would be a weight differential resulting from the differential due densities of hot and cold air, or pressure differntial due to outside wind patterns. The force generated by temperature or pressure differentials between inside and outside will induce air movement which can be utilized to bring outside air in for ventilating purposes. This may result in a negative energy flow when evaluated in terms of space heat, however, certain quantitites of outside air must be introduced to interior environments in any case. If not done in this manner, it will require the use of source fuel to operate fan motors. This convected transfer of energy can also be used as the device to transfer energy through a skin which otherwise has a high resistance to flow. Thus, a skin with high thermal resistance when sealed against air penetration will have a low overall resistance when air is allowed to pass through it.

Radiated energy is highly susceptible to absorption or reflection and travels primarily in straight lines making its control a relatively simple matter. The problem comes primarily when it is to be used in an environment where the conducted and convected transfer has to be controlled. This requires the use of a material which is transparent to radiation but resistant to conduction and convection. In general, materials with high radiational transparency have low resistance to conduction. The most typical example of this is glass.

The Ideal Building Skin

An ideal building skin could be described as follows:

1. It would permit total penetration of all radiant energy striking it, but would have the capability of selectively reducing all or part of the entire spectrum or specific portions of the spectrum. The selective reduction of the entire spectrum permits the modulation of total energy gain which, in the end, is equivalent to heat gain control. By selectively filtering portions of the spectrum it permits radiation in a useful range to enter while barring that which is counter-productive, as in the case of admitting visible light radiation while filtering infrared during the summer yielding natural light from solar radiation (about 25 percent of total) while keeping out unwanted heat. Providing means to limit this natural light input to those levels which are actually desired minimizes the heat energy which inevitably results from the presence of light.

2. The skin would have a total resistance to conducted energy transfer and be impervious to air penetration, thus eliminating convected losses. It would have the capability of having its thermal resistance varied permitting free conducted flow of energy if the outside ambient temperature

was closer to the desired inside condition than the prevailing one. The skin would also be able to admit as much air as would naturally flow through a completely unencumbered area of equivalent size.

A number of these performance characteristics are impractical to achieve, some are virtually impossible, and an assembly which approached all these requirements would be prohibitively expensive. It might, in fact, consume more energy in construction than would be saved in operation. There are, however, a number of alternatives which would approximate this condition and which are relatively simple to execute. As in other cases, however, approaches can be illustrated most easily by citing prototypical solutions to a hypothetical situation.

Solar Heating Factors

This consideration must be based on a number of factors which can only be analyzed in total at the time a specific building design is undertaken including:

a) Site limitations on orientation.

b) Solar micro-climate, i.e., local shading factors due to adjacent buildings, to topography, etc., typical local wind patterns.

c) Use patterns anticipated both daily and annually.

d) Degree of dependability of user adjustment.

A wall component responding to the performance standards previously listed has been designed and evaluated.

PROTOTYPICAL EXAMPLE 1: FACADES RECEIVING SUFFICIENT INSOLATION TO MAKE SOLAR HEATING VIABLE

Assume a 10'-6" floor to floor dimension dimension and a 10'-6" x 12'-0" skin module (figure d-3/6). The portion below the window sill line functions as a typical thermosiphoning panel (section d-5, Solar Energy). The upper portion of the module is divided into two functions. The center portion is a chase which collects the hot air from the entire lower portion, adds some additional solar heat and discharges the heat from the top, either into the room or to the outside, depending on the setting of a damper. The side portions are openable windows with shutters on the outside which serve both as thermal and solar control.* The shutters are insulated, tight fitting and reflective on the outside. On easterly and westerly exposures, they operate vertically, opening on the north side. On the south, they are horizontal, awning type. By selecting the appropriate degree of opening, direct solar radiation can be either reflected into the room or outwards.

*The term "thermal shutters" will be used to describe all devices that can be closed to reduce heat transfer between inside and out, such as louvers, dampers, rolladen, sliding panels and even insulating draperies.

d-3/5
Building Skin

For the following sections, these factors will be used (areas are per 10'-6" x 12'-0" module):

1. Total thermo-siphon area 90 sf

2. Total operable window area 35 sf

3. U-factor for thermo-siphon area when not in operation .06 (based on 4" rigid insulation, air space and cover plate)

4. U-factor for window area with shutters open 1.13

5. U-factor for windows with shutters closed 0.18 (based on 1" rigid insulation, air space and 1 thickness glass)

6. Average January daily insolation:

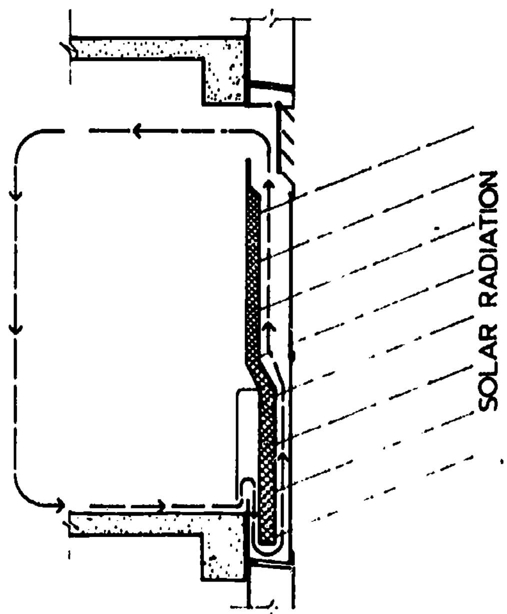
East & West	372 btu/sf
Southeast & Southwest	645 btu/sf
South	828 btu/sf

(While there is some insolation for North exposure even when there is no direct solar radiation, it is not high enough to warrant the installation of collectors on this facade).

Heating Season

The damper is set to direct solar heated air inward.

FIGURE d-3/1:
THERMO-SIPHONING
PANEL
HEATING POSITION



The windows are closed and the shutters are open wide enough to reflect sunlight into the room. Taking operation from 9 AM to 3 PM, we see the following heat flow patterns:

East and West - For about 3 hours/day the thermo-siphoning panels receive sun totaling about 372 btu/sf or a total of 33,500 btu/module/day. With an overall efficiency of about 20 percent, this results in the delivery of about 6700 btu/day/module. The operating efficiency takes into account the heat loss from the panel so that heat gain is net for

the operating period. During the other three hours when the school is in operation, the panel acts as a typical wall with a U-factor of 0.06. If the average outside temperature is 33° F and the inside temperature is 68° F, the heat loss for those three hours will be:

$$(90)\ (.06)\ (35)\ (3) = 567 \text{ btu/module}$$

The U-factor for windows is 1.13; consequently, for the six hours in question, the heat loss will be:

$$(35)\ (1.13)\ (35)\ (6) = 8305 \text{ btu}$$

When there is insuffient insolation, the back draft damper automatically shuts down the thermo-siphon. At night the shutters are manually closed. This results in a closed wall with an average U-factor of:

$$(90/125)\ @\ .06 = .043$$

$$(35/125)\ @\ .18 = \underline{.050}$$

$$\text{Average U} = .093$$

Assume an average outside temperature of 20° F and an inside temperature of 60° F (building is allowed to "coast"). For eighteen hours this will give a total heat loss of:

$$(125)\ (.093)\ (40)\ (18) = 8370 \text{ btu}$$

The total conducted heat loss will be 17,242 btu/day/module. If the heat gain from the solar collector is included, the net daily loss is:

10,542 btu/module

If the building skin were of conventional type, assuming high quality insulation in the opaque portions and 25 percent single glazing, the same area would have the following daily heat loss for the same assumed conditions:

$$(125 \times .25)(1.13)(35)(6) = 7{,}415$$

$$(125 \times .75)(0.06)(35)(6) = 1{,}181$$

$$(125 \times .25)(1.13)(40)(18) = 25{,}425$$

$$(125 \times .75)(0.06)(40)(18) = \underline{4{,}050}$$

38,071 btu/module
(10'-6"x 12'-0")

In both cases, solar gain from the windows has been ignored.

The collectors on the same prototypical skin module on a SE or SW exposure would be expected to produce about 11,610

btu/module. This would result in a net heat loss of 5,632 btu/module.

For a south exposure, the expected daily heat production is 14,904 btu/module resulting in a net loss of only 2,338 btu/module.

No allowance has so far been made for the heat demand which results from the introduction of required outside air. If it is assumed that one module will enclose the area used by fifteen students, the total quantity of outside air introduced during the typical six-hour operation period will be:

(15 students)(5 cfm/student)(6x60 minutes) = 27,000 cubic feet/module

The heating load resulting from this outside air will be:

$(27,000)(.018)(\Delta t) = 486\ \Delta t$ btu/module

or, for the time under consideration:

17,010 btu/module

This demand for heat due to introduction of outside air is important since it can be seen that in the most extreme heating demand conditions the skin module in the south orientation can replace virtually all the conducted heat loss with the solar collectors. In February, the insolation on a south wall will average 785 btu/sf/day. One module's collectors could be expected to produce 17,170 btu/day which is virtually equal to the total conducted loss under the outside temperature conditions assumed in the previous example.

Supplementary Ventilation

When the prime consideration is the prevention of excessive heat rise due to solar and internal loads, the damper is reset to direct air from the collector outward. Thus, as

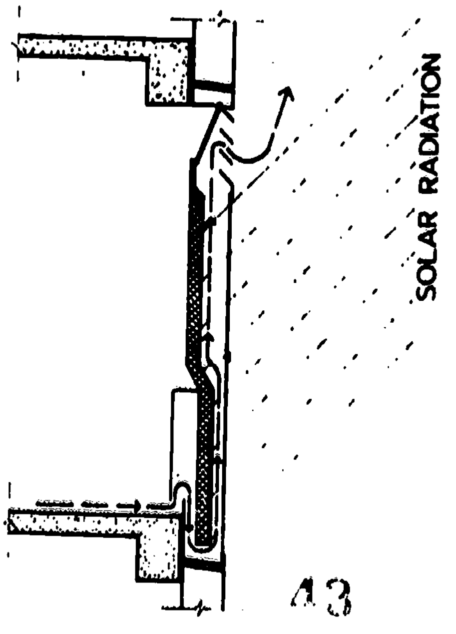


FIGURE d-3/2: THERMO-SIPHONING PANEL VENTILATING POSITION

the sun heats the air in the thermo-siphoning panel, it rises and exhausts, drawing make-up air from the room. This air can be provided from open windows or from the corridor. This air movement has the additional advantage of drawing off heat that would normally be absorbed by the building and of functioning most actively when the need due to solar loading is the greatest.

PROTOTYPICAL EXAMPLE 2: FACADES RECEIVING INSUFFICIENT INSULATION TO MAKE SOLAR HEATING VIABLE

Assume a 10'-6" floor to floor height. For rooms which require light (that is, virtually all occupied spaces) provide continuous windows from 3'-0" to 8'-0" above floor level and fit these windows with thermal shutters. These windows will provide light to a 10'-0" strip of floor area, an average of about 6 hours/day and, assuming shutters will be open about 8 hours/day, the wall will have an average daily U-factor of 0.27.

Average U-factor with shutters open:

$$(5.0/10.5)(1.13) + (5.5/10.5)(.06) = .57$$

Average U-factor with shutters closed:

$$(5.0/10.5)(.18) + (5.5/10.5)(.06) = .12$$

Average Daily U-factor:

$$(8/24)(.57) + (16/24)(.12) = 0.27$$

Note: In evaluating the use of artificial light where heating is a criterion, one factor frequently cited in favor of artifical light is that the associated heat tends to reduce the load on the heating plant and that reduction, in conjunction with improved U-factors made possible by the elimination of glass outweighs the energy savings resulting from natural lighting. This argument tends to ignore the heat associated with natural (solar) light which is actually about the same as for fluorescent light (section d-5, Solar Energy).

Take one lineal foot of wall 10'-6" high. Compare wall "A" with average U-factor of 0.1 providing no natural light and wall "B" with average daytime U-factor of .57 and thermal shutters, providing light to a ten foot deep strip of floor area for six hours/day average. (Assume shutters open eight hours/day, similar U-factors for two walls with shutters closed, average daytime temperature differential of 20° F, 120 operating, heating days and 200 total operating days).

Wall A - The seasonal conducted heat loss from one lineal foot of wall when room is in use will be:

$$(10.5)(0.1)(20)(8)(120) = 20{,}160 \text{ btu}$$

If this heat loss is replaced by a system with 60 percent

efficiency, it will require 33,600 btu source energy.

Wall B - The total seasonal conducted heat loss from one lineal foot of wall occurring where room is in use (shutters open) will be:

(10.5) (.57) (20) (8) (120) = 114,912 btu

If this heat loss is replaced by a system with 60 percent efficiency, it will require 191,520 btu source energy.

If these windows replace 1.5 watts/sf over 10 sf floor area for six hours per day average, the total savings will be:

(10) (1.5) (6) (200) = 18,000 wh

At local generating rates, this represents:

(18,000) (12.4) (1.1) = 245,520 btu source energy

Thus, Wall A has a net negative flow of 33,600 btu and Wall B a net positive flow of 245,520 - 191,520 = 54,000 btu. In terms of the factors discussed above, the use of Wall B would result in savings in source fuel amounting to about 87,600 btu/lineal foot/yr.

The two wall systems described here are intended to show an approach to designing non-mechanical components of a building to reduce energy use. They are not intended to be in any way definitive solutions to building skins.

Computer simulation, using an hourly weather tape would be useful in determining specific applicability. The time when heat is required in the building versus the ability of the thermo-siphoning collectors to provide that heat is an important factor in evaluating the suitability of the scheme for school use. Figures d-3/3 and d-3/4 indicate the complexity of the problem.

FIGURE d-3/3:
HEAT CONTRIBUTIONS
FROM VARIOUS
SOURCES
EAST EXPOSURE

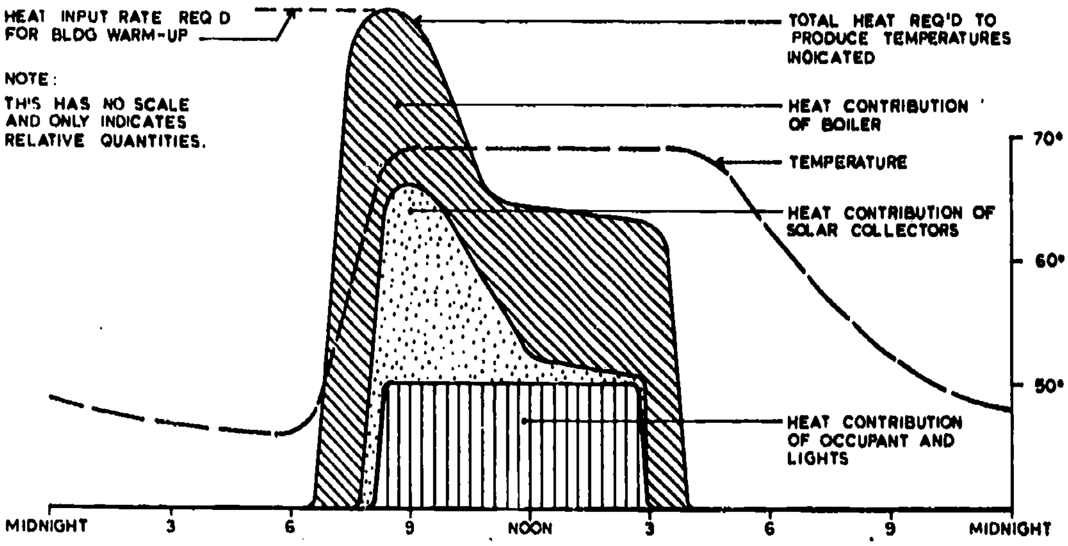
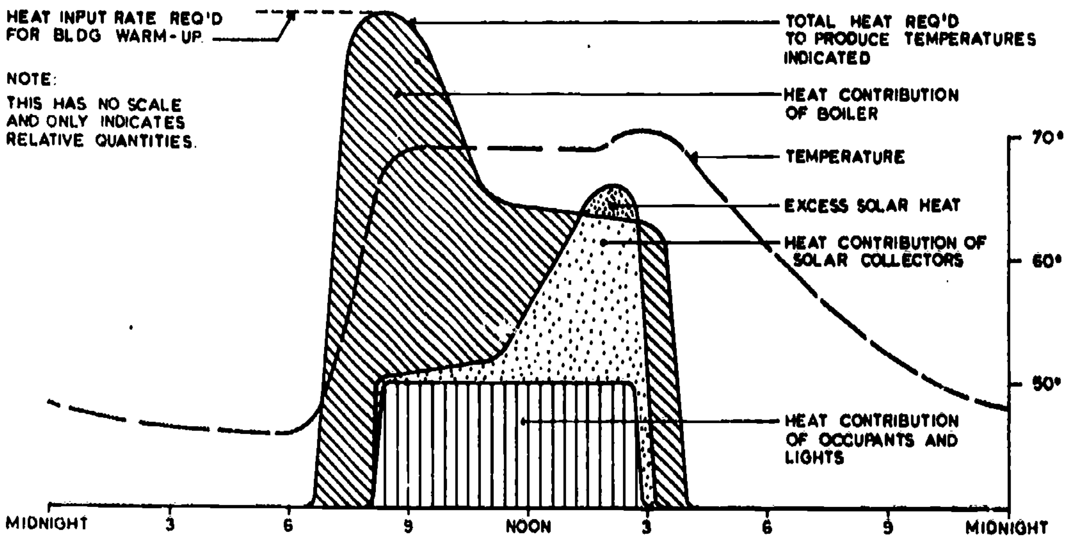
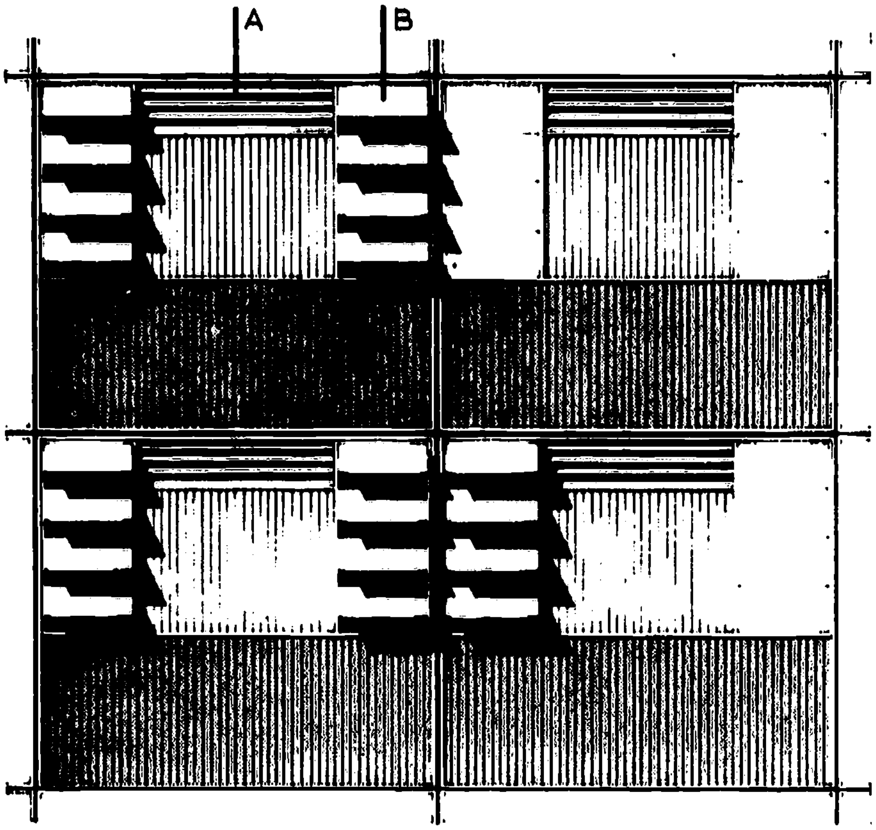


FIGURE d-3/4:
HEAT CONTRIBUTIONS
FROM VARIOUS
SOURCES
WEST EXPOSURE



South Elevation



East Elevation or
West Elevation
(opposite hand)

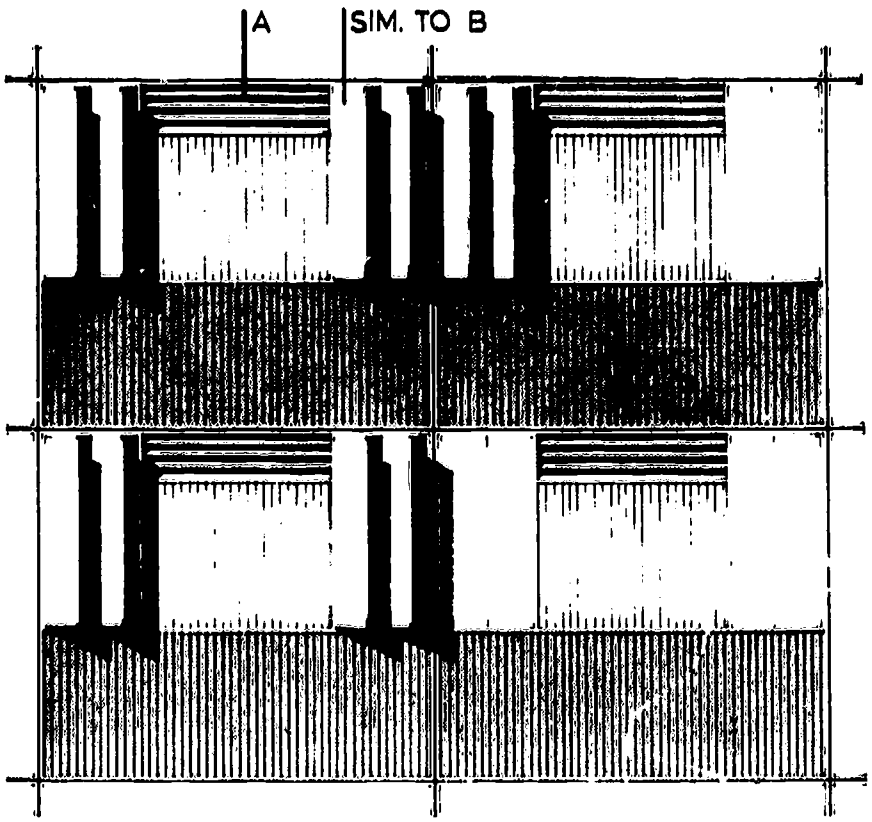


FIGURE d-3/5:
PROTOTYPICAL
BUILDING SKIN

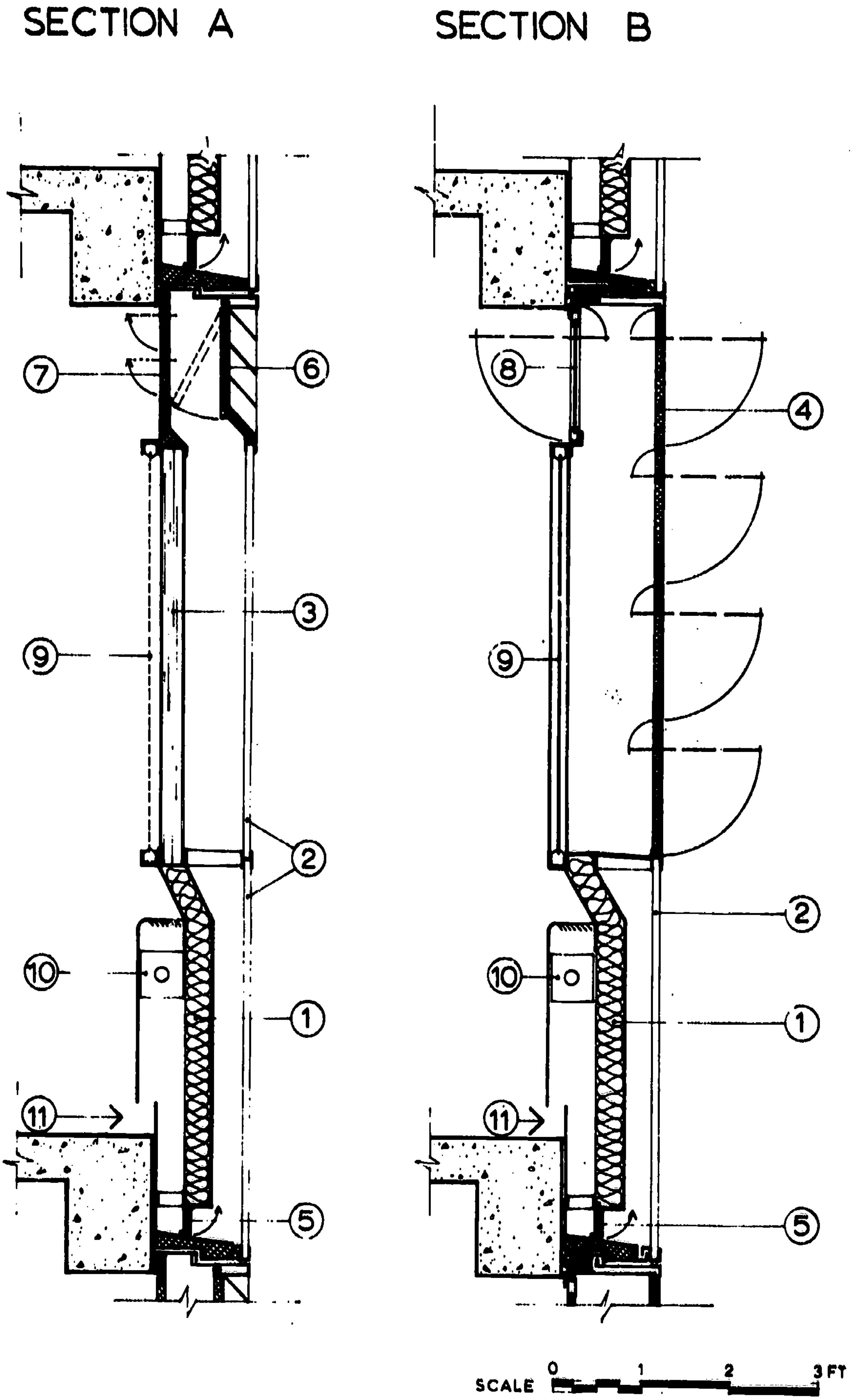


FIGURE d-3/6:
PROTOTYPE
BUILDING SKIN

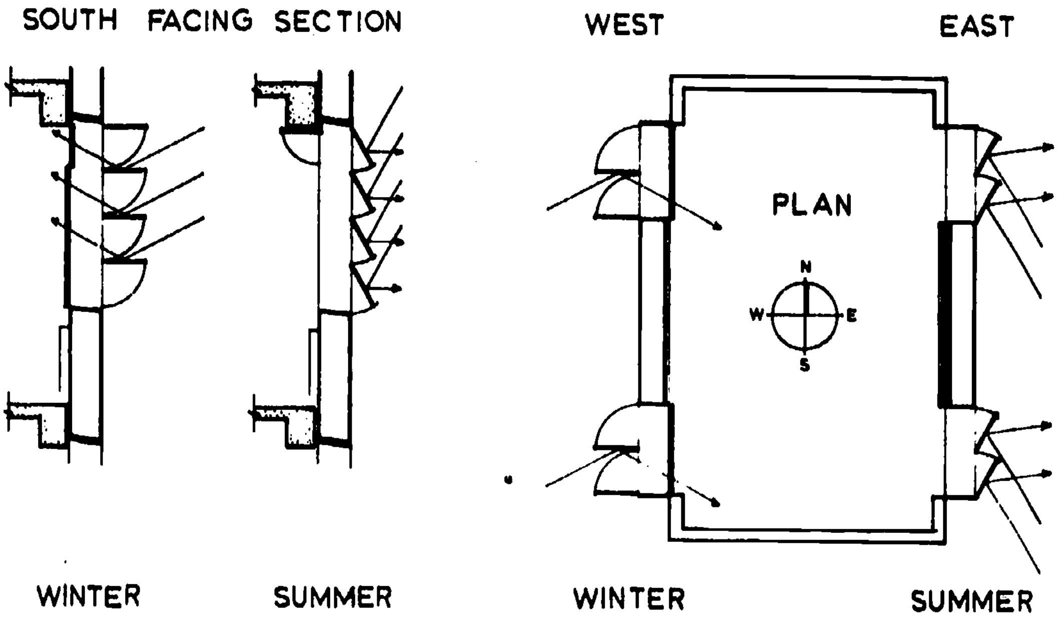
(1) Collector plate with absorptive surface, backed with insulation.

(2) Transparent, corrugated fiberglass

(3) Translucent insulating panel.

(4) Thermal-solar shutters (Reflective surface, backed with 1" rigid insulation shown closed. Dotted lines indicate full open position). Sections are taken through south facing elevations. (For East and West facing elevations, vertical shutters will be used). During winter the shutters can be used to reflect light into the room while the room is occupied. During summer, the shutters can be used to reflect heat off building.

FIGURE d-3/7:
SEASONAL POSITION
OF SHUTTERS



(5) Back draft damper automatically closes to prevent reverse flow.

(6) Manually operated damper shown in heating cycle position, directing solar warmed air into the room. When in dotted position, air is discharged through this louver to the outside.

(7) Self-operating insulated flaps, automatically close to prevent reverse flow.

(8) Vent window.

(9) Sliding glass window for ventilation can be moved behind translucent insulating panel (3) (shown dotted).

(10) Conventional convector.

LEGEND FOR
FIGURE d-3/6

(11) Entry for room air to be heated by thermo-siphoning collector and/or convector.

Summary of Findings

1. Desirable characteristics of the building envelope are a high resistance to unwanted thermal transfer and an ability to utilize natural light, ventilation and solar heat when available and desired.

2. Provide an average roof U-factor of 0.06.

3. Provide an average wall U-factor of 0.15. 0.15 is the average of all wall, window and door surfaces based on the use of thermal shutters as follows:

Opaque wall	64%, U = 0.06 = 0.0384
Windows (thermal shutters closed)	35%, U = 0.30 = 0.1050
Doors	1%, U = 0.60 = 0.0060
	0.1494
	SAY: 0.15

Opaque wall	64%, U = 0.06 = 0.0384
Windows (thermal shutters open)	35%, U = 1.13 = 0.3955
Doors	1%, U = 0.60 = 0.0060
	0.4399
	SAY: 0.44

Note: These factors are for walls with thermal shutters <u>only</u>. Overall wall thermal performance is to result in an average U-factor of 0.32 without requiring shutters.

4. Provide windows to permit natural lighting to be utilized for ambient lighting throughout ten-foot deep perimeter zone.

5. Provide insulated shutters at windows to prevent excessive heat loss when the light transmitting properties of the glass are not required.

6. Provide solar shading to prevent excessive heat gain when it is not desired.

7. Provide an average U-factor of 0.14 for slabs between heated and unheated spaces.

8. Provide slab on grade with vertical edge insulation with total average U-factor of 0.12.

d-4

prototypical proposals

4 ● THERMAL MASS

a) Evaluate advantages of low thermal mass construction during heating season.

b) Evaluate advantages of high thermal mass construction during cooling season.

c) Select high or low thermal mass approach based on trade-offs between a) and b) above evaluated throughout an entire operating season.

Definition of Thermal Mass

Thermal mass refers to the heat storage capacity of the materials of a building. It is a characteristic that is independent of the insulating quality of the structure. It is, in effect, an energy reservoir which delays the impact of energy input or outflow. This is due to the fact that a specific quantity of energy will create a smaller temperature rise in a large mass than it will in a small mass.

This characteristic of large thermal mass structures can serve a positive function in the summer by reducing the temperature rise in a building during the day by storing some of the heat and then releasing it at night. It can also serve a positive function during the winter, if the internal and solar heat gains are greater than the total heat loss. In this case, if the building had no thermal mass, the temperature would continue to rise above acceptable limits which would, in turn, require rejecting the excess heat to the outside where it would be lost. Storing some of this heat within the structure permits the building to "coast" for a longer period after these heat gains have been removed.

The drawback to high thermal mass occurs when a mechanical system is required to move a building's temperature from one level to another. Under these conditions, energy must be expended to fill or empty this energy reservoir. This energy is in excess of that which is required to heat or cool the air to the desired level.

d-4/2
Thermal Mass

The ability of a building to provide a predetermined thermal environment in the face of widely varying exterior conditions is due in part to the thermal mass of the structure, that is, the capacity of the building to store heat energy at some set temperature. It must be stressed that thermal mass and thermal resistance (insulation) are distinct from each other. It is entirely possible to have a building with high insulation and low thermal mass.

The contribution of thermal mass to energy conservation varies substantially with the interrelationship of use and exterior environmental cycles. The three examples (figures d-4/1, d-4/2, d-4/3) shown indicate trends only and are not intended to show actual conditions.

For the purpose of demonstration a school day from 9:00 AM to 3:00 PM is used. The assumed acceptable indoor temperature range is 65° F to 75° F for winter, 60° F to 80° F for summer. Where the temperature level is being mechanically maintained, a highly responsive system is assumed which does not substantially over-supply its service.

Example: Winter Characteristics

In the winter example, starting the cycle at 3:00 PM, heating plants are shut down and the buildings begin to cool.* With identical insulating properties, the initial heat flow is the same for both the high and low thermal mass buildings. The low thermal mass building however, will experience more rapid temperature drop due to the fact that it contains less heat. As the interior temperatures fall, the temperature differentials will also decrease (allowing for changing outside temperature) but that of the low thermal mass building will decrease more rapidly, resulting in a more rapidly decreasing rate of heat loss. Both buildings will continue to lose heat until heating plants are activated in the morning. The amount of heat that must be introduced to reach the minimum acceptable level will be the same as that lost during the night, plus that lost during the

*It is actually current practice in NYC schools to shut down heating plants earlier. However, if the building is actually at minimum temperature and the heat loss is greater than the heat gain, heating must be provided as long as the school is in operation. What in fact happens is that schools tend to be somewhat overheated. The heat input from lights and occupants slows the temperature drop. Thus, if the building is heated five degrees above the minimum acceptable temperature, it will be some time after the heating plant is shut off before that minimum is reached. This permits end of day coasting while remaining within acceptable bounds. However, the over-heating produces a temperature differential which is greater than necessary, which in turn increases heat loss.

heat-up period. Assuming plants of equal size, it will be necessary to activate the system in the high thermal mass building earlier due to these factors:

1. It has lost more heat during the night so more heat must be reintroduced.

2. It is starting at a higher temperature, so the temperature differential is greater resulting in a more rapid heat loss during heat-up period.

3. The earlier start-up, resulting from the first two conditions, further delays the achievement of design temperature because as the building is heated, the temperature differential increases, increasing heat loss and decreasing the rate of temperature gain.

Thermal Mass Temperature Analogy

It may seem paradoxical that one building starting at a higher temperature than another takes more heat to achieve a similar end temperature; however, the following analogy may be useful.

> Buildings function as energy vessels. These may be considered as containers of water. The temperatures are represented by the levels, the heat loss is represented by leaks at the bottom of the containers, and the temperature differentials are represented by the height of the water above the leak (figure d-4/4). As the height of the water increases, the pressure on the leak increases and the flow of water increases. If the size of the holes in both containers is the same, the container having the higher water level will leak faster. If the two containers are filled to the same level and allowed to stand, they will begin leaking at the same rate; however, the smaller one's level will fall faster thereby reducing the pressure on the leak and reducing the rate of flow. It can be seen that even though the level of the smaller container drops more rapidly, the actual water lost is less. If similar faucets represent the sources of heat needed to reestablish the original (daytime) temperatures, it can be seen that the large container will take longer to refill and that during the refilling time, the rate of loss will be increasing.

In the original example, once the buildings achieve their minimum operating temperatures, the rate of heat loss will be the same for each with just enough input to make up for the loss. The condition is analogous to the two containers receiving water at the same rate as the loss. If

they are at the same level, the input and output will be the same. The flow will continue in this fashion until the systems are shut down at 3:00 PM which completes the daily cycle.

As stated earlier, this discussion is based on a situation where the internal and solar gains are less than the heat loss, requiring the input of mechanical heat. If these factors are greater than the loss, the picture changes. In this case, the temperatures will continue to rise without the input of the heating system. The temperature in the low thermal mass building will rise faster than that of the one with high thermal mass. As long as the temperature remains within the acceptable limits, it will be useful permitting the building to coast further when these heat sources are removed. In this case, however, the low thermal mass building will have the greater heat loss due to the higher temperature differential. If the temperatures exceed the acceptable conditions some heat will have to be discharged (the equivalent of letting water spill over the top of the container) and this is waste energy in the sense that it is available but not useful at the time it is available.

Example: Summer Characteristics

The summer situation is somewhat different, although related. The analogy would be the same two containers, partially full and partially submerged in water (figures d-4/5 and d-4/6.

At 3:00 PM the buildings are cooler than the ambient air but since they are unoccupied, the temperatures are allowed to rise, the high thermal mass building rising more slowly. As the outside temperature drops below the building temperature, the building temperatures drop; again, the one with high thermal mass, more slowly. At some point in the morning, the outside temperature will again pass above those inside, and the inside temperatures will begin to rise towards the pre-established limit. When they reach the limit, the cooling systems must be introduced if the limit is to be held.

In the water example, this would be represented by use of a pump which would remove enough water to prevent its rising above a preset level. It is possible that either the high or low mass building might reach this level first; however, once the level is reached, the rate of cooling required will be the same, since the rate of incoming heat is a factor of temperature differential and insulation.

Example: Spring and Fall Characteristics

During the spring and fall when outside temperatures range above and below the inside temperature, the high thermal mass will have any advantage that may exist. This is due to the stabilizing effect of the mass.

Selection of High or Low Thermal Mass

To a large degree, the thermal mass of a building is not subject to manipulation; however, there are choices in the selection of structure, closure, partitions and other systems. The determination of whether high or low thermal mass should be sought will be a function of the following:

1. Local climate

2. Site factors such as shading

3. Acceptable (design) interior conditions

4. Operating patterns and schedules

Modification of Thermal Mass

There are, in addition to selection of building systems, means of increasing thermal mass by introducing high mass material into the building envelope. In some cases this material has been installed in such a way that it can be moved inside or out of the building shell as the situation changes. This has been accomplished, for example, by the use of two sets of large tanks with connecting piping, one set inside the building and one set out. When weather and use conditions favor a high thermal mass, water fills the inside tanks. When low thermal mass is preferable, the water is pumped to the outer set and stored. In addition, by shifting the water on a daily cycle, it is possible to collect heat on one side of the building skin and release it on the other. For example, in the summertime, water which is inside during the day will pick up heat from the building and store it at the inside temperature. At night, when outside temperatures fall below what the inside temperature had been, this water can be pumped to the outside tanks, where it will lose this heat to the air and night sky. In a system of this type, care must be taken to ensure that the source fuel required to power pumps, control systems, etc. is less than that which would be used to achieve the same results by direct mechanical processes.

The effective thermal mass can also be changed by use of materials (generally salts) which absorb or release large amounts of heat when they change state. These materials are able to store large amounts of energy at preselected temperatures using relatively small physical masses. Several other advantages also exist.

Selecting a material which changes state at a low temperature will permit the storage of low temperature heat energy. That is, a material which changes state at 78° F, for example, can store energy from an 80° F environment and release it to a 76° F environment. In practical terms, this could serve a double function. During heating seasons it would collect and store the excess heat energy from lights, occupants, etc. which would tend to raise the interior temperature above acceptable limits and release it before the temperature dropped below acceptable limits.

During the cooling season, these salts would absorb large quantities of energy, preventing the inside temperatures from exceeding desired limits and, if exposed to the outside, release this energy when ambient temperatures are about 74° F (a condition frequently occurring during summer nights). The use of these salts in buildings is beginning to receive serious study. Although it is currently difficult to assess the feasibility of their use, it is possible that within the next six months, development and general availability will permit their inclusion.

Summary of Findings

1. The selection of structural, closure and partitioning systems will have an effect on thermal mass which is independent of thermal transmission characteristics.

2. High thermal mass building will perform with less fuel use when outside temperatures swing above and below acceptable inside temperatures (summer). Low thermal mass building will perform better when outside temperatures remain consistently above or below acceptable inside temperatures (winter). In selecting one or the other, trade-offs between the seasonal difference must be weighed.

3. The choice of high or low thermal mass construction will have to be evaluated at the time of actual building design, using a computer simulation reflecting actual scheduling, program, site, etc.

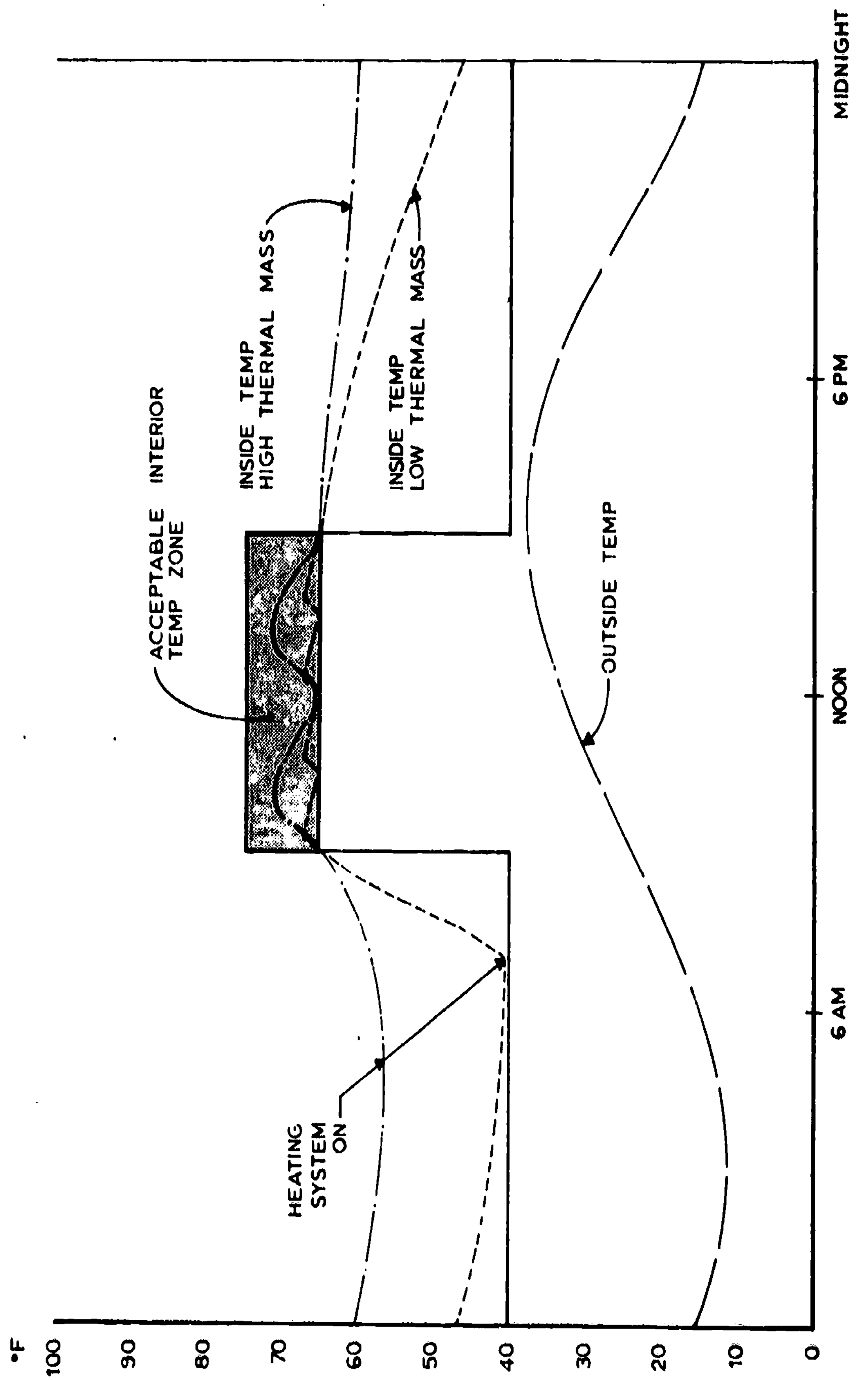


FIGURE d-4/1
THERMAL MASS
COMPARISON
WINTER TEMPERATURE
PATTERN

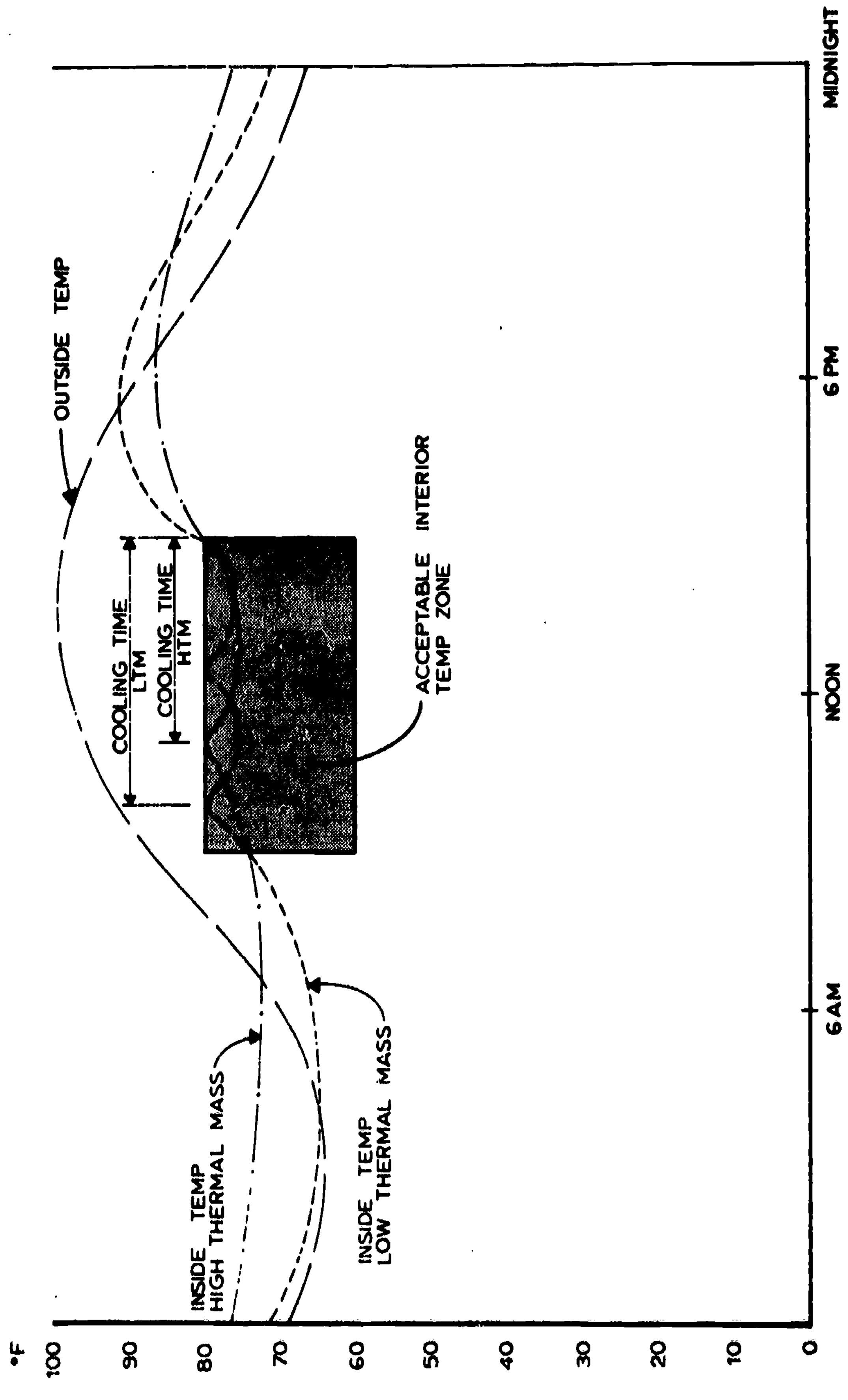


FIGURE d-4/2
THERMAL MASS
COMPARISON
SUMMER TEMPERATURE
PATTERN

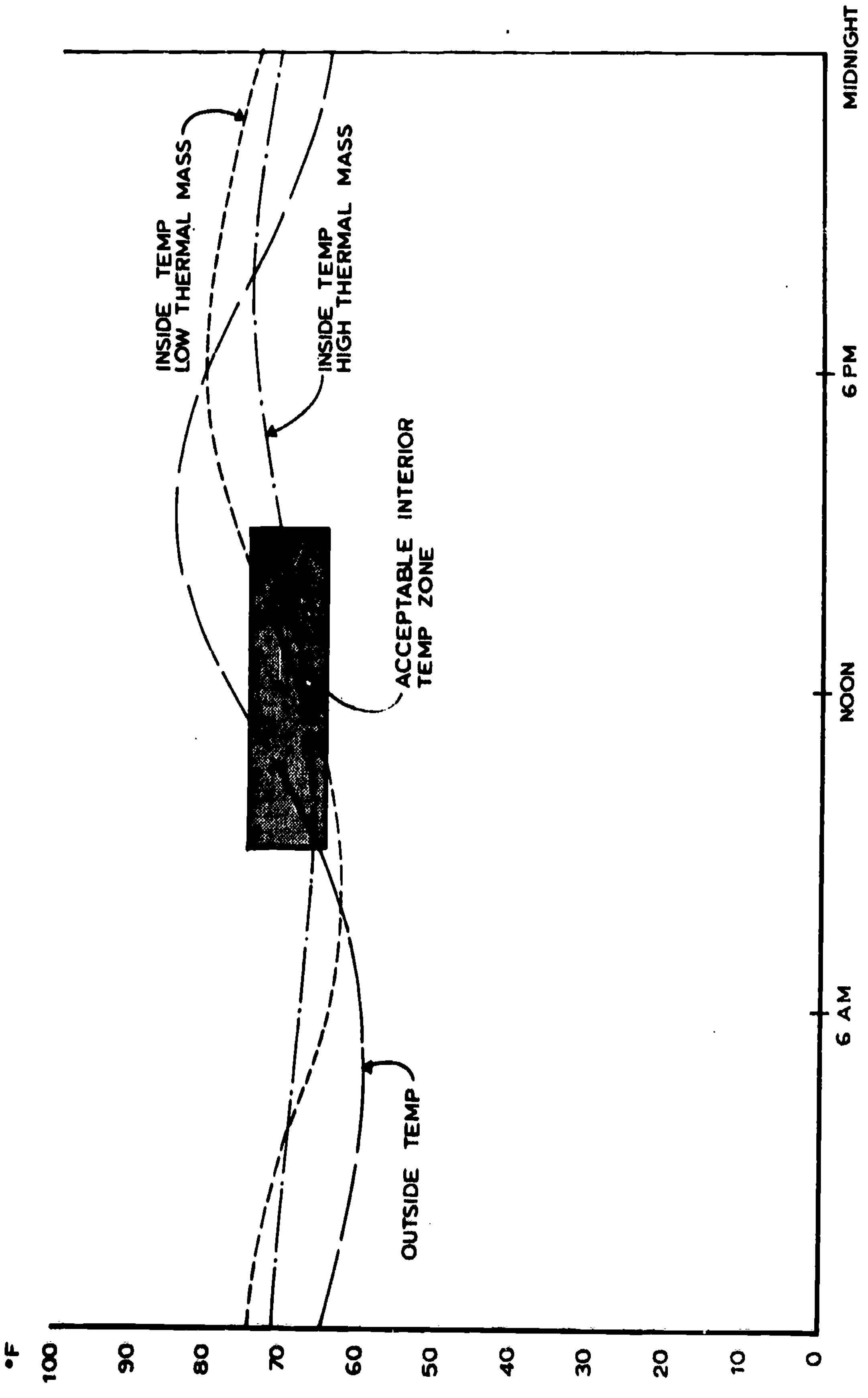


FIGURE d-4/3
THERMAL MASS
COMPARISON
SPRING-FALL
TEMPERATURE
PATTERN

3:00 PM
Supplies Are Turned Off. Both Leak At Equal Rate.

Midnight
Supplies Still Off. 'A' Has Greater Rate Of Loss Than 'B' Due To Higher Level.

5:00 AM
Supply 'A' Is Turned On Full To Overcome Night Loss. 'A' Must Replace More Water Than 'B'.

7:00 AM
Supply 'B' Is Also Turned On Full. Both Supplies Are Replacing Night Loss. Rate of Loss From 'A' Is Greater Than That of 'B'.

9:00 AM
Both 'A' And 'B' Reach Operating Level. Supply Is At Maintenance Rate, Equals Rate of Loss.

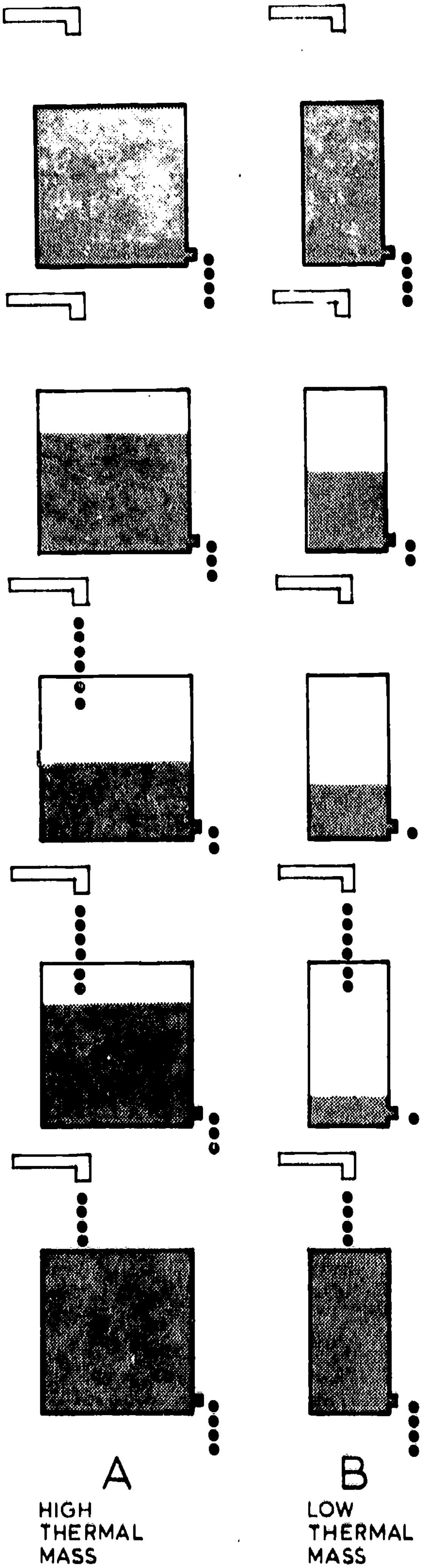
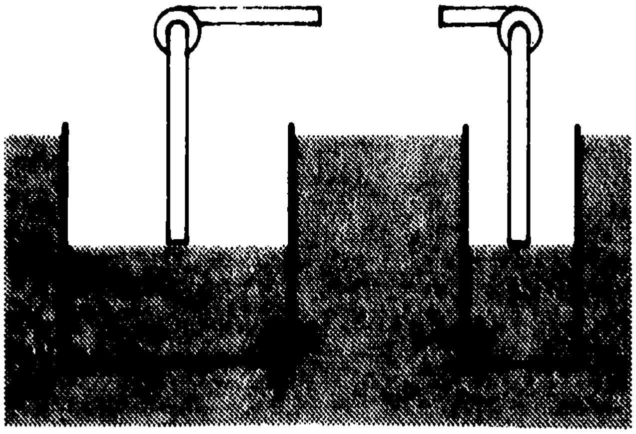
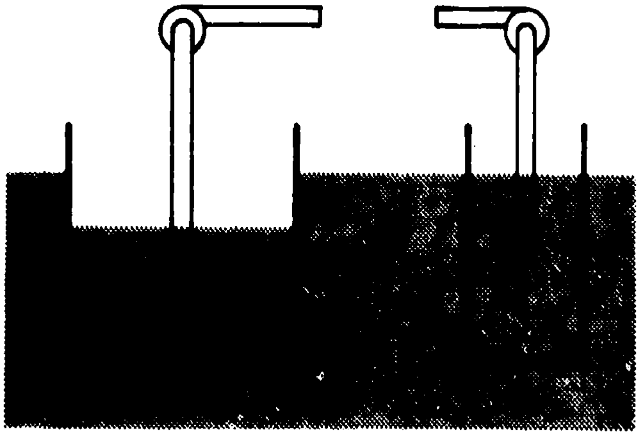


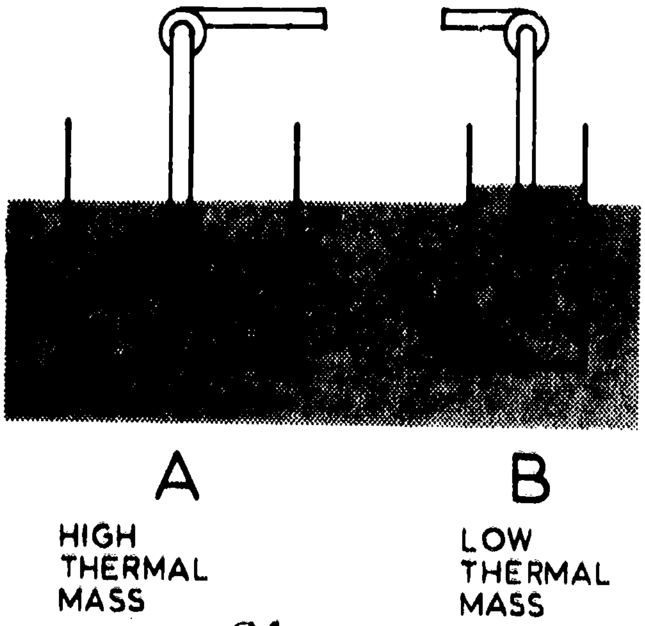
FIGURE d-4/4:
THERMAL MASS
WINTER ANALOGY



3:00 PM
Both Pumps Turned Off. Inside Levels Rise.



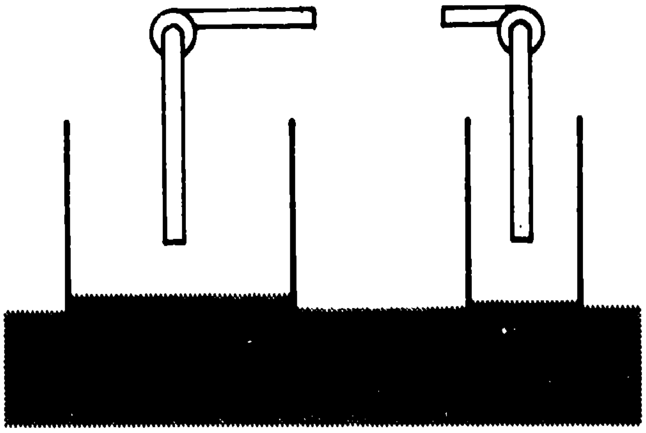
6:30 PM
Outside Level Dropped. Both Inside Levels Continue To Rise. 'B' Rises Faster, And Equals Outside Level.



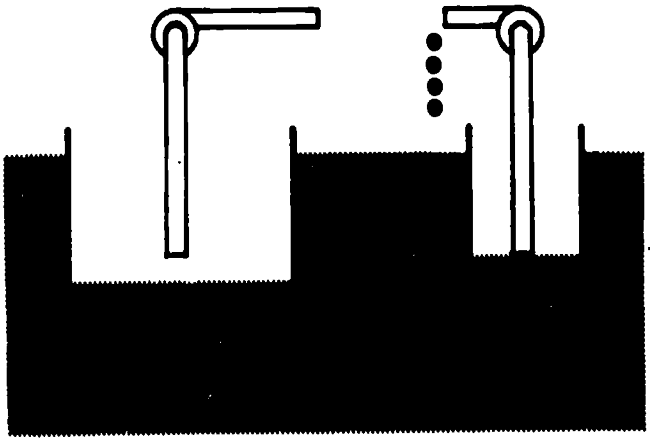
7:00 PM
Outside Level Dropped, Equals 'A' And Is Lower Than 'B'. 'B' Flows Outward.

FIGURE d-4/5:
THERMAL MASS
SUMMER ANALOGY 1

Midnight.
Outside Level Continues to Drop. Inside Levels Both Drop.



9:30 AM
Outside Level Rises. 'B' Fills Up Faster Than 'A' And Reaches Maximum Acceptable Operating Level. Pump 'B' Starts Removing Water.



10:30 AM
'A' Reaches Maximum Operating Level. Both Pumps Run at Same Rate to Maintain this Maximum Level.

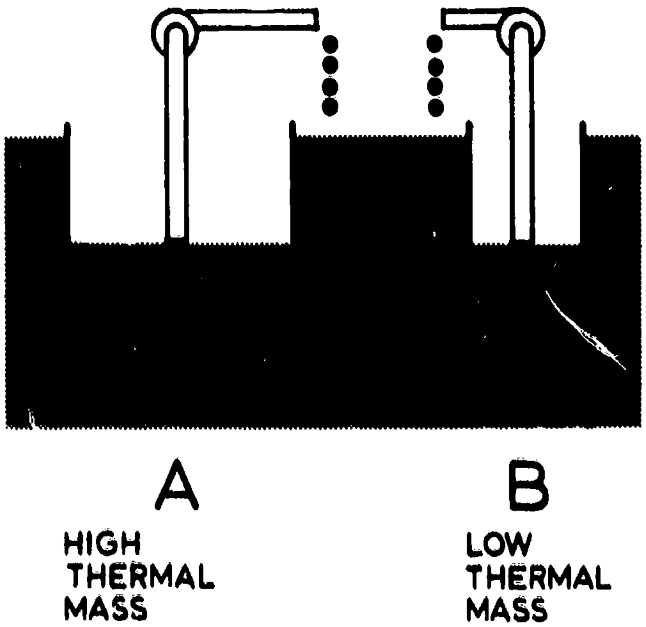


FIGURE d-4/6: THERMAL MASS SUMMER ANALOGY 2

d-5

prototypical proposals

5 ● SOLAR ENERGY *

a) Utilize solar energy when available to perform functions that would normally require the commitment of fossil fuel or nuclear energy resources.

b) Avoid unnecessary, unwanted heat loss, and heat gain, at the solar collector.

c) Avoid unnecessary complexity in construction that would tend to result in a device which would not be executed as designed with a consequent loss in operating performance.

d) Avoid unnecessary complexity in operation that would tend to prevent function as designed with a consequent loss in operating performance.

Most of the principles that lead to building forms that are responsive to natural forces take advantage of solar energy in one form or another. The use of prevailing winds for natural ventilation is a response to air movements caused by the differential solar heating of the earth's surface. The admission of winter sun for heating while screening out unwanted summer sun is a response to direct solar radiation and to changes in ambient conditions. The use of a building's mass to absorb the sun's heat during the day and to release it at night serves the dual function of limiting maximum daytime temperatures during the hot seasons and minimum nighttime temperatures during cold seasons. The use of daylight for task illumination within a building employs the visible light of solar energy in place of the fuel which would otherwise be required to generate the electricity for lighting.

*Section prepared with assistance of TOTAL ENVIRONMENTAL ACTION (TEA), Harrisville, New Hampshire. Portion on "Insolation Quantities" was extracted from TEA's solar energy feasibility study prepared for this report.

Solar Energy

This section deals primarily with the use of the radiant energy from the sun. The effects of wind on building and system design are discussed in 'Cooling', (section d-8) and 'Ventilation', (section d-9). The effects of building mass on interior environments are covered in 'Thermal Mass', (section d-4). The direct use of solar radiation is to some extent limited by the necessity to use the energy immediately and at the point of introduction, and by the difficulty of storing it. Techniques have been developed which widen the applicability of sol r energy. Most commonly, solar energy is introduced into a transfer medium such as air or water and distributed to areas remote from the collection point.

Heat Storage

Since the availability of solar energy at any local spot is somewhat unpredictable, particularly in the New York area, provisions must be made either to store energy from the sun or to provide alternative sources when solar energy is not available.

Storage of energy requires that a reservoir of desired capacity exist. This reservoir may store energy in any of a number of forms; however, heat is the simplest and most common. The direct storage of heat requires a considerable mass of the storage medium, varying according to the thermal mass of the medium. For example, for water to store the energy equivalent of burning one gallon of #6 oil, it would be necessary to raise the temperature of one hundred seventy-five gallons of water 100° F. To put it differently, a school which relies on a boiler with a 60 gallon per hour burner would require a water storage tank of 10,000 gallons to store one hour's worth of heat at a 100° F water temperature differential.

Considering the difficulties presented by storage requirements, it seems desirable that where solar energy is to be used, it be used as a supplemental energy source to reduce fossil fuel demand. Methods of utilization will have to be compatible with the prime source and must have a cost which reflects the limited output.

Greenhouse Effect

Most forms of solar collection are based on utilization of the so-called greenhouse effect. This is due to the fact that glass has a high transmission rate of short wave energy (solar radiation) and a high resistance to long wave energy (heat). Thus, solar radiation is freely transmitted through glass and strikes an absorbing body where it is converted to heat. The hot body then radiates heat back toward the glass. The long wave energy is contained, preventing most of the reradiation from leaving the collector. A transfer medium, usually either water or air, is used to take the energy from the point of collection to the point of use.

Several means for solar collection using complex

Solar Energy

technology are currently in existence. Focusing collectors use reflectors or lenses to concentrate the sun's rays on to the heat transfer medium. They have the advantage of being able to achieve temperatures in excess of 1,000° F, but they capture only the direct rays of the sun and must be constantly aimed in order to achieve maximum efficiency. Various forms of photo cells convert solar energy directly into electrical energy. These cells have very low conversion efficiencies at present. Both approaches are currently extremely expensive, and as such, will not be considered for this study. However, since this is a new area of research and development, they should be borne in mind for future application should the cost factors change.

Bio-Conversion

Another area of solar collection is in bio-conversion. This approach takes the natural process of photo-synthesis to develop organic energy sources from solar radiation. It is currently applicable primarily on either a very small or very large scale, not on the level of an individual school except that heat generating machines may at some future time be fueled by organic substances such as alcohol or methane rather than fossil fuels.

Collector Types

This study will, therefore, examine three basic collector types and several functions for which the energy can be used:

1. Flat plate with water transfer medium
2. Flat plate with air transfer medium
3. Windows

Flat Plate Collectors

The two flat plate collectors capture energy in the form of heat. Therefore, requirements must be found within the school for heat energy. These are limited primarily to space heating which is seasonal and domestic hot water which is a year round requirement. In addition, absorption units can be used to convert heat energy into cooling although at this time, the output temperatures from flat plate collectors are marginal for use in absorption machines.

Windows

Windows capture solar radiation in the form of heat and of light which eventually becomes heat. In this way, when heat is desirable, the energy is in effect used twice. Normally, however, the limitation in the use of windows for solar capture is that the energy is limited to one area of the building.

Flat Plate Water Collector

This device is basically one or more sheets of glass covering an insulated space backed with a radiation absorbing surface and some means of passing water through or across this surface to remove heat energy to be used at some remote location. This is generally done by providing channels for water integrally with the back plate (either by soldering tubing to the plate or, forming the plate with integral internal routes) or permitting water to run across

the face of the back plate and collecting the heated water in a reservoir at the bottom of the collector. Some more complex collectors have been built with an assembly similar to an automobile radiator where water carrying tubes pass through fins increasing the capability to absorb heat. Temperatures in flat plate collectors may reach 350° F or higher however, the effective output temperatures are considerably lower with greatest efficiency occurring at the lowest output temperatures. This is due to (1) increased flow of heat energy into the transfer medium when the temperature differential between the collector and the medium is greatest and (2) to the decreased flow between the system and the ambient environment when the temperature differential is least. An output temperature of 140° F is a good working figure that can achieve relatively high efficiency (about 40%) with simple collectors.

Heat Pump Supplement

Water at this temperature cannot be introduced into a conventional hot water heating system. One method of utilizing it is to increase its temperature by means of a heat pump. This method of heating requires a large number of complex components. In addition, due to the ratio of fuel input to electrical output, the actual fuel requirement for the system may, in fact, be higher than for the direct use of fossil fuel.

> Heat pump performance is described as the amount of heat energy pumped versus the amount of energy required to do the work of pumping. An efficiency of 2½ to 3 is common. At an efficiency of 3, for example, for every kwh (3,412 btu) consumed by pump, it would create a temperature change that would permit 10,236 btu to be taken from the low temperature medium and delivered to another medium at a usable high temperature. Current electricity generating practices in this area require about 13,650 btu/delivered kwh. Therefore, extracting 10,236 btu from a solar system utilizing a heat pump requires 13,650 btu input at the generating station (at this point mostly fossil fuel) or an efficiency of 75%. This form of "solar heating" has, in fact, a fossil fuel utilization rate not much different from a well-run conventional heating plant. For these reasons, it seems an unwise choice.

This low temperature water could also be used to preheat domestic hot water from street main temperatures (about 50° F to 100° F) prior to fossil fuel heating, to preheat incoming ventilation air, or in radiant heating systems in floors or ceilings.

Pre-heating of Domestic Hot Water

Domestic hot water appears to account for the use of about 10% of the fuel oil used annually in NYC schools or about 50 gallons of oil/msf/yr. If this is the case and half of this could be saved by solar pre-heating, the potential for saving 25 gallons of oil/msf/yr seems feasible. Assuming a 200 day operating year, this would require the input of an average of 10,875 btu/msf/day.

$$\frac{(25 \text{ gallons of oil/yr} \times 145{,}000 \text{ btu/gal} \times .60 \text{ efficiency})}{200 \text{ days/yr}}$$

Using figure d-5/5 (Insolation on South-Facing Surfaces), we find an average of 920 btu/sf/day falling on a 60 degree tilted collector in December. If the collector were 40% efficient, we could expect about 370 btu/sf/day output or a requirement of 30 sf of collector to pre-heat the water for 1,000 sf of building area. In this case, however, for most of the year, the output of the collector would not be used to full capacity.

If, instead, the system were designed to meet full demand when insolation was 1,200 btu/sf/day (around April), at 40% the output would be 480 btu/sf/day. This would require 23 sf of collector/msf. Again, (figure d-5/5) this would provide all the heat required for all months except November, December, January and February, in which months they would provide 80%, 77%, 81% and 97% of the total requirement. The average capability, taking the other months at 100% would be 94.5% or, instead of saving about 25 gallons/yr, the savings would be 23.6 gallons/yr. Thus, a reduction in collector area of 23% causes a reduction in effective output of only 6%.

At current prices, 23.6 gallons cost about $8.25. Current manufactured collectors cost in the range of $10 to $15 per sf installed, or $230 to $345 for 23 sf. This makes the installation of such a system on a purely economic basis highly questionable. This is based on today's fuel prices. Although it is difficult to predict price trends, virtually all informed sources expect a minimum of a 10 percent per year escalation rate for the forseeable future and some expect long term rates as high as 25 percent. If the escalation rates are only 10 percent, the average cost over a twenty year period for oil will be almost exactly $1.00/gallon. If, at the time of construction the cost of collectors is $10 per square foot, the factors under consideration will be a $230 in estment to achieve a $23.60 annual savings. If financing costs are 6 percent, the pay back time will be about 16 years, at 7 percent it will be about 18 years and at 8 percent it will be about 21 years. As a study and testing device, a solar collector (20-25 sf collector area per msf floor area) to pre-heat domestic hot water seems to be a worthwhile installation. This item would add an estimated $0.25/sf to the initial cost of the building.

It should be noted that the possibility exists for defraying all or part of the cost of solar installations through subsidies for research in this area. This is especially true of this project since it will be carefully instrumented and its performance monitored.

Passive Air Medium Collector

There are a number of ways in which solar energy is used passively. Many are unconsciously installed in conventional building procedure. Windows capture light and heat although in general, somewhat indiscriminately. The simplest form of collector specifically designed to capture heat is the thermo-siphoning panel. This panel is composed of a transparent cover plate, an air space, and a solar radiation absorbing back plate with openings at the top and bottom. Solar radiation heats the back plate, which in turn heats the air in the air space. This air rises and is discharged out of the top opening creating a lower pressure in the air space. This in turn brings air in through the bottom opening. As the heated air in the room cools, it falls and is reintroduced into the panel in a continuous operation. The basic panel has no moving parts and will supplement any conventional heating system whenever the temperature in the collector is greater than the room temperature.

Thermo-Siphoning Efficiency

There are two basic problems with thermo-siphoning collectors. First, their efficiency is low compared to other types. Around 20% of the solar energy falling on them is delivered as heat. This is due to the relatively small amount of thermal mass available for heat transfer represented by the air which is moved through the collector by convection. The second problem is that when the temperature in the collector falls below that in the room, the device works in reverse. This can be overcome by using check dampers (figure d-5/2).

Thermo-siphoning collectors can, with relative ease, be integrated into building walls. In this case, the orientation of the building has an obvious effect on the performance of the system. The variation between south and southeast or southwest exposures is about 1: 0.75 (figure d-5/7). Assume, for example, a south exposure wall. The incident solar energy during the heating season is about 165,000 btu/sf (figure d-5/7). If a thermo-siphoning collector operates at 20% efficiency, this provides 33,000 btu/sf/season. If the system is totally passive, this will function even when the school is unoccupied and will serve to reduce the start-up heating loads after weekends and vacations. About 0.4 gallons of oil would be consumed by a boiler to produce the amount of heat that could be provided by one square foot of solar collector during the heating season.

The design for a typical thermo-siphoning wall assembly is included in this report (section d-3) along with evaluations and recommendations.

Windows as Solar Collectors

This section will evaluate windows as solar collectors only in terms of applications of solar radiation although the use of open windows to augment base ventilation levels constitutes an indirect use of solar energy (section d-9).

The prime drawback of windows is that glass has poor resistance to thermal conduction. As a result, during cold weather, a substantial amount of heat is lost to the outside even though there is also considerable solar gain. The trade-offs of the conducted loss versus the desirable gains were made with the following results:

1. On a seasonal basis, single-glazed windows on south, southeast and southwest exposures reduce overall heating loads. Double-glazed windows on east and west exposures also reduce heating load.

2. Solar lighting in itself will result in a reduction of source fuel use on any exposure if provided by windows with adequate thermal shutters.

*The term "thermal shutters" will be used to describe all devices that can be closed to reduce heat transfer between inside and out, such as louvers, dampers, rolladen, sliding panels and insulating draperies.

3. The cooling load usually associated with solar heat gain through glass during warm seasons is no greater than the load created by providing the same amount of light using fluorescent fixtures.

4. Trade-offs between advantages and disadvantages of windows in specific situations must be individually analyzed. It is important in these analyses to recognize all of the positive aspects of windows to the overall energy use picture.

Daily Heating Efficiency for Single-Glazed Windows

The efficiency of a window as a heating solar collector can be described as the ratio of the solar radiation transmitted by the glass to the interior less the heat lost by conduction to the exterior divided by the total incident solar radiation.

$$\text{Daily } E = \frac{R_{td} - 24U\Delta t}{R_{id}}$$

where E = Efficiency

R_{td} = Transmitted solar radiation (daily)

R_{id} = Incident solar radiation (daily)

U = "U" factor of window assembly

Δt = Temperature differential

It is obvious that the efficiency will vary from day to

day as Δt and R_{id} vary according to local weather conditions; however, it is useful to look at a typical example to see the general energy flow patterns. Average daily insolation on a south-facing window in January is about 850 btu/sf (figures d-5/5 and d-5/7). Assume an average Δt for a 24 hour period of 40° F, a transmittance for the glass of 90% (single-glazed), and a U-factor of 1.15.

$$E = \frac{(0.9)(850) - 24\ (1.15)(40)}{850}$$

$$E = -40\%$$

This indicates that more heat is lost by conduction than is gained from the sun.

Seasonal Heating Efficiency for Single-Glazed Windows

This ratio is for a situation at the extreme end of the heating season. The efficiency on a seasonal basis is quite different.

$$\text{Seasonal } E = \frac{R_{ts} - 24\ D\ U \Delta t_s}{R_{is}}$$

where R_{ts} = Transmitted solar radiation (seasonal)

R_{is} = Incident solar radiation (seasonal)

D = Days in heating season

Δt_s = Average seasonal temperature differential

Note: In a school with night shutdown, the average Δt will be somewhat less than the differential between design interior and average outside temperatures due to cooler nighttime temperatures. On the basis of this and a 4,800 degree day season, take Δt to be 22° F.

$$\text{Seasonal } E = \frac{(0.9)(165{,}000) - 24\ (182)(1.15)(22)}{165{,}000}$$

Seasonal E = 23% for south-facing window

$$\text{Seasonal } E = \frac{(0.9)(137{,}000) - 24\ (182)(1.15)(22)}{137{,}000}$$

Seasonal E = 9% for southeast or southwest facing windows

$$\text{Seasonal } E = \frac{(0.9)(92{,}000) - 24\ (182)(1.15)(22)}{92{,}000}$$

Seasonal E = -30% for east or west exposures

Two ways in which the efficiency of a window as a solar collector can be improved are (1) double-glazing and (2) thermal shutters. Both of these act to reduce the loss of energy due to conduction. The following examples refer to

the original situation described where $\Delta t = 40^\circ$ F.

Daily Heating Efficiency for Double-Glazed Windows

Double-Glazing (South Exposure)

$$E = \frac{R_t - 24\,(U)(\Delta t)}{R}$$

$$E = \frac{(0.80)(850) - 24\,(0.67)(40)}{850}$$

$$E = 4\%$$

This, although small, indicates a positive net heat gain even during a relatively extreme heating situation.

Daily Heating Efficiency for Windows with Thermal Shutters

Thermal Shutters with Single-Glazing (South Exposure) Since this device is not entirely passive, some basic assumptions will have to be made regarding scheduling.

1. School operates 5 days/wk.
2. Shutters will be open from 9 AM to 5 PM when school is in use.
3. Outside temperature will be 15 degrees warmer during the time that shutters are open than when they are closed.

Then:

$$E = \frac{R_t - \left[5/7(H_o)(U_o)\Delta t_1 + 5/7(H_c)(U_c)\Delta t_2 + 2/7(24)(U_c)\Delta t_3\right]}{R_i}$$

where: H_o = Hours/day shutters open when school is in use.

H_c = Hours/day shutters closed when school is in use.

U_o = "U" factor with the shutters open.

U_c = "U" factor with the shutters closed.

Δt_1 = Temperature differential for portion of day with shutters open when school is in use.

Δt_2 = Temperature differential for portion of day with shutters closed when school is in use.

Δt_3 = Average temperature differential on days when school is closed.

$$E = \frac{\frac{5}{7}(0.9)(850) - \left[\frac{5}{7}(8)(1.15)(33) + \frac{5}{7}(16)(0.1)(48) + \frac{2}{7}(24)(0.1)(40)\right]}{850}$$

$$E = 29\%$$

Using the preceeding approaches, similar savings can be realized for seasonal efficiencies. It should be pointed out that these figures are relative and should not be taken as design factors.

Solar Lighting

The use of windows as solar collectors for light is also significant. If one assumes even the relatively low figure of 1.5 w/sf for energy required for lighting, the following situations occur.

Electricity Savings from Natural Lighting versus Heat Loss from Glass

A five foot high window with a sill three feet above the floor can, under most daylight conditions, provide light ten feet into a room. Thus, 5 sf of window area lights 10 sf of floor area for about 6 hours/day on the average. In a 200- day operating year, 5 sf of glass provides the light that would otherwise require

$$El_1 = (T)\ (D)\ (A_f)\ (L)$$

where: El_1 = Electricity for lighting

T = Hours/day lights are used

D = Days/yr of school

A_f = Floor area under construction

l = Lighting load (w/sf)

$$El_1 = (6)\ (200)\ (10)\ (1.5)$$

$$= 18{,}000 \text{ w/yr}$$

$$= 18 \text{ kwh/yr Electricity Saved}$$

The seasonal conducted heat losses (L) for 5 sf of glass are:

<u>For single and double glass</u>

$$L = A_g 5/7(T_{op})(182)(U)\Delta t_1 + 5/7(T_{sh})(182)(U)\Delta t_2 + 2/7(24)(182)(U)\Delta t_3$$

Where A_g = Area of glass

T_{op} = Hours of plant operation in days when school is in use.

T_{sh} = Hours with plant shut down on days when school is in use.

Δt_1 = Daytime temperature differential ($68^oF - 48^oF = 20^oF$)

Δt_2 = Nighttime temperature differential on days when plant is shut down. ($53^oF - 33^oF = 20^oF$)

Δt_3 = Average temperature differential on days when plant is shut down. ($53^oF - 40^oF = 13^oF$)

Note: Assume interior temperature falls 15° F during plant shutdown period.

For thermal shutters

$$L = A_g \left[\frac{5}{7}(T_{op})(182)(U_o)\Delta t_1 + \frac{5}{7}(T_{sh})(182)(U_c)\Delta t_2 + \frac{2}{7}(24)(182)(U_c)\Delta t_3\right]$$

Consider heating plant and shutter operation schedules to be coordinated:

Heat loss for single glass

$$L = 5\left[\frac{5}{7}(8)(182)(1.15)(20) + \frac{5}{7}(16)(182)(1.15)(20) + \frac{2}{7}(24)(182)(1.15)(13)\right]$$

L = 452,000 btu/yr

Heat loss for double glass

$$L = 5\left[\frac{5}{7}(8)(182)(.67)(20) + \frac{5}{7}(16)(182)(.67)(20) + \frac{2}{7}(24)(182)(.67)(13)\right]$$

L = 263,000 btu/yr

Heat loss for thermal shutters with single glass

$$L = 5\left[\frac{5}{7}(8)(182)(1.15)(20) + \frac{5}{7}(16)(182)(0.1)(20) + \frac{2}{7}(24)(182)(0.1)(13)\right]$$

L = 148,000 btu/yr

Energy input required to make up heat losses if these losses are made up by a system with 60% efficiency:

753,000 btu for single glass

438,000 btu for double glass

247,000 btu for thermal shutters

An opaque wall with a U-factor of 0.1 would have a seasonal heat loss of about 36,000 btu for the same 5 square feet which would require an added input of 60,000 btu. The added heat loss during the winter season resulting from the use of natural lighting is:

693,000 btu for single glass

378,000 btu for double glass

187,000 btu for thermal shutters

These figures can be compared with the energy required to generate the required lighting: 246,000 btu to generate 18 kwh (local heat rate of 12,400 btu/kwh + 10% transmission loss).

When the other positive energy characteristics of windows are also taken into account, the net result is to reduce the total source fuel by the selective use of windows.

Undesirable Heat Gain from Solar Radiation Used for Lighting

About 25 percent of the energy in solar radiation striking the earth's surface falls within the visible spectrum. If the entire solar spectrum is introduced into an environment to provide lighting, the heat gain for any light level will be the same as for a system which, within the space, is 25 percent efficient. A fluorescent light fixture is about 22 percent efficient in converting electric energy into visible light, so for any given light level, the heat gain characteristics of solar and fluorescent fixtures will be about the same. If a filter is provided which permits the passage only of the visible spectrum and absorbs the remaining radiant energy, the resulting heat can be channeled to areas where it is needed or discharged to the outside.

Summary of Findings

On the basis of the preceeding data, we recommend that the following direct applications of solar energy be utilized in the prototype building:

1. Provide a flat plate water solar collector supplying a heat exchanger to preheat domestic hot water. Careful metering of this system will provide data to permit more accurate evaluation of solar energy systems in the New York City area.

2. Provide passive thermo-siphoning wall panels (may be installed selectively for comparison and evaluation) for heating as described in 'Building Skin' (section d-3).

In addition, the entire building must be carefully evaluated as a solar collector.

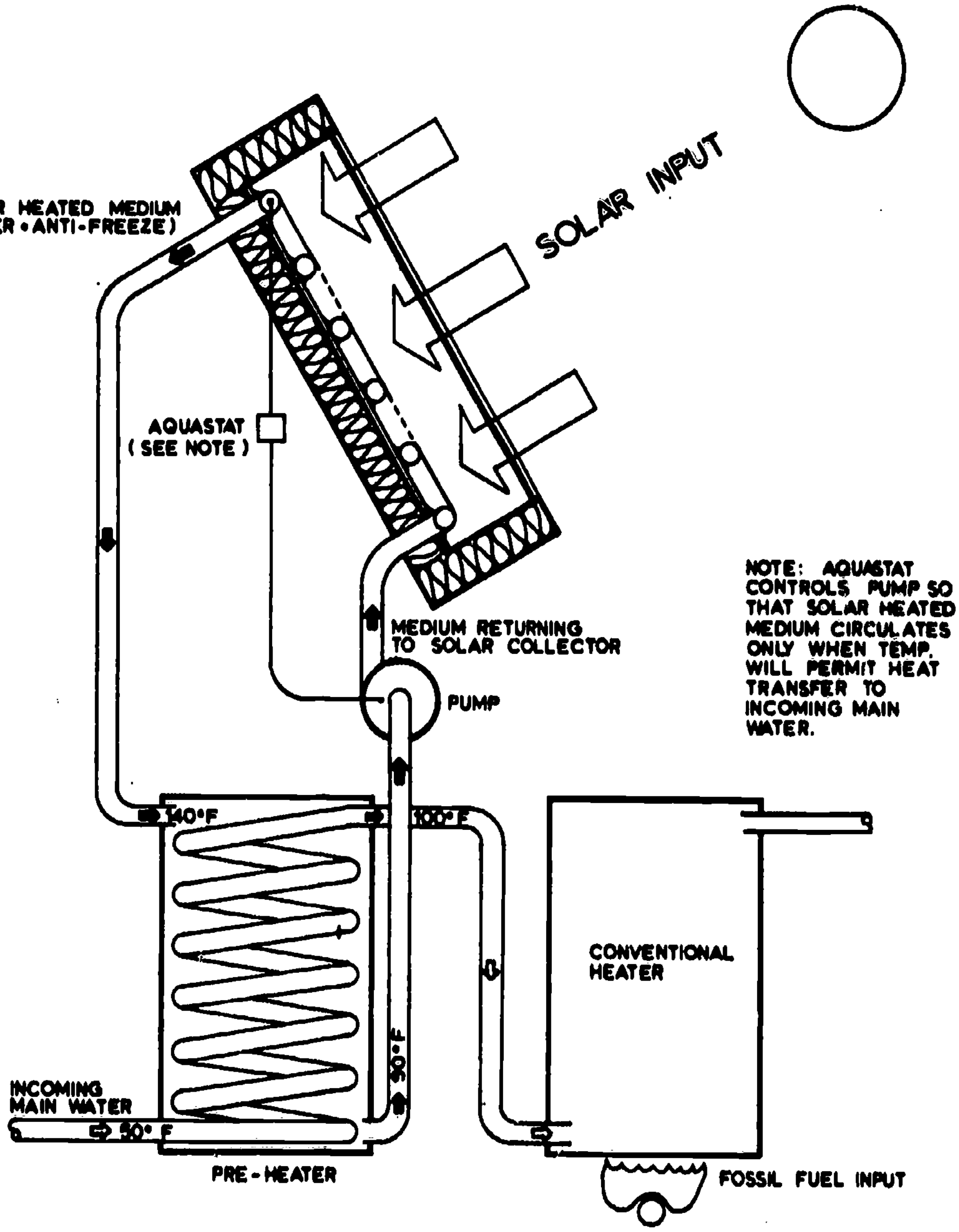


FIGURE d-5/1:
SOLAR PRE-HEATER
FOR DOMESTIC HOT
WATER (FLAT PLATE,
WATER-MEDIUM
COLLECTOR)

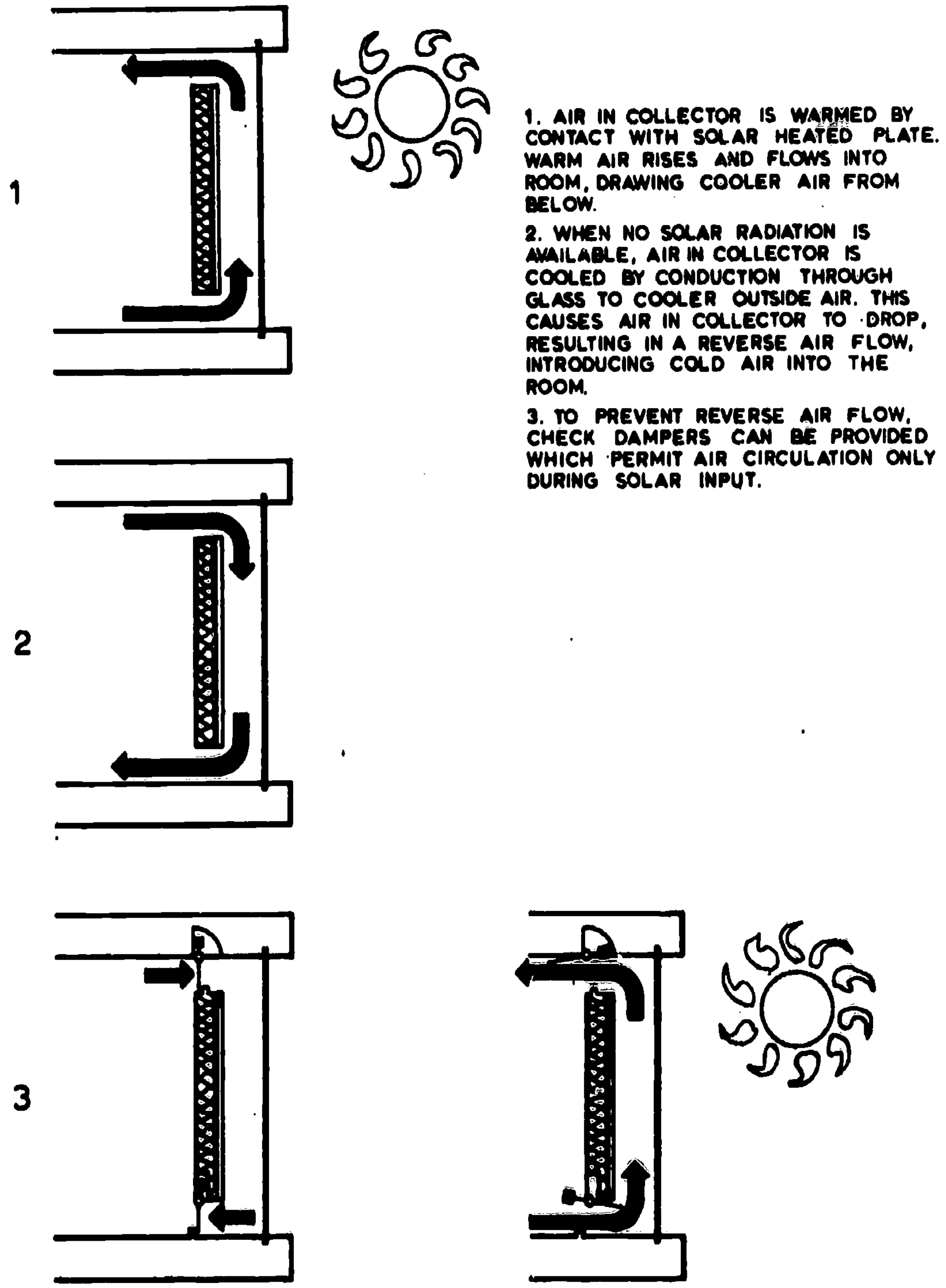


FIGURE d-5/2:
SOLAR SPACE HEATER
(FLAT PLATE, AIR-
MEDIUM, THERMO-SIPH-
ONING COLLECTOR)

INSOLATION QUANTITIES

Study prepared for this report by Total Environmental Action (TEA)

Weather and Collector Performance

The two most important factc 's in analyzing the performance of collectors as a function of weather, are temperature (in most cases using degree days) and solar radiation (measured in btu's per square foot per time period). When working with and designing with natural energy systems, it is important to realize that since weather conditions vary greatly from hour to hour and day to day, monthly and yearly, a system designed for averages may not perform according to expectations when the system is used during a period of non-average conditions. In addition, solar data are very difficult to obtain, both because of the imprecise instruments which have been used for the last 20 or 30 years to measure solar radiation, and also because of the rather small number of weather stations (approximately 75 in the United States) which measure solar radiation (as with temperature, this varies greatly from one location to another although the distances may be small between those locations). Because of the unpredictable availability of solar energy, the use of the sun's energy must be looked upon, with today's design parameters, as a bonus or supplement to other sources of energy. It is possible that, in the future the wide fluctuations in solar energy may be more easily dealt with through the use of very long-term storage systems.

Precise calculations of solar weather are less important than is usually assumed since variations in solar radiation of say 10% change overall efficiency of a solar system as little as 3% out of a total overall efficiency of 40%. In addition, the collectors will not always be running when the sun is shining for a number of reasons, not the least of which is that there are times when the sun is shining and heat is simply not needed. Other times are during early morning and late evening when the sun's intensity is not great enough to be collected and when the angle of the sun's rays to the collectors is so low most of the sun is reflected off of the panel. Yet other times are during partly sunny periods when clouds break only for short times. During the course of a six-month heating season, approximately 25% of the total solar radiation which hits the collector will hit it when the system is not in operation.

Types of Weather Data

Finding and using weather data for solar energy utilization design is not an easy task. There are several types of data available, but none are directly suited to needs of solar heat design, and there are no easy methods to convert the data to more useable forms. We have compiled data from several different sources, and have done some of our own computations to derive further data. These data are listed in figures d-5/3, d-5/4, d-5/5, d-5/7. This discussion deals with the meaning and usefulness of these various data types.

Probably the most accessible data are the ASHRAE Solar Heat Gain Factors (SHGF), taken from their Handbook of Fundamentals. These factors are based on theoretical calculations of radiation, and are designed primarily for the sizing of cooling equipment; they are not as useable as it might first appear. SHGF's assume: (1) a typical cloudless day on the 21st of the month (conversion must be made for higher or lower clearness locations such as high altitude or industrial atmospheres) and (2) transmission of heat through a single pane of double strength glass (with a particular specified transmittance, reflectance, and absorptance). SHGF's take into account for any particular orientation, direct solar radiation, diffuse sky radiation, solar angle, and ground reflectivity. ASHRAE uses them to determine time and magnitude of maximum heat gain for computing maximum cooling load in buildings. This necessitates picking the maximum hour. Used in this way, SHGF's are invaluable. They can also give a useful value for whole day solar heat gain on any given latitude, month, and orientation. Beyond that, however, their usefulness is limited. For example, there is no accurate way to take the SHGF for a day and convert it into a monthly or yearly heat gain. Times and amounts of cloudiness are much too variable for this to be done with any confidence. Other data must be used in predicting longer term expectations from the sun.

The most accessible data from the Weather Bureau, in terms of number of stations taking readings over long time periods, is sunshine and cloudiness data. For stations recording sunshine, a machine records minutes during the day when there is enough sunshine to essentially cast a shadow. This is recorded as hours of sunshine and percent of possible sunshine. Cloudiness is recorded hourly, from sunrise to sunset, in tenths of the sky covered. These readings are averaged to give an overall cloudiness figure. Both sunshine and cloudiness data are of limited useability in determining solar insolation over time because the rate of insolation is so variable, depending on time of day. Neither sunshine nor cloudiness data say anything about distribution during the day, so estimates based on them will at best be approximate, and at worst totally misleading.

The most useable form of data, speaking on a strictly relative scale, is solar radiation data from the weather bureau. They have long-term reports of radiation on a horizontal surface measured in Langleys (cal. cm.$^{-2}$). The number of stations recording this data is limited to about 75 (only 40 stations appear in some of the long-term summaries), and there are many problems of calibration and accuracy, so many that the weather bureau stopped publishing radiation data summaries in 1972. The data does, however, provide the only hard information on what actually gets through the atmosphere in useable form, and the long-term means are probably the most accurate indications of how much energy is available in recording locations under average conditions (which may not necessarily be common

conditions).

For solar radiation data to be useable for solar heating calculations, it must be converted from the horizontal (where the data was recorded), to the azimuth and tilt of the intended collection surface. The recorded data is a combination of direct solar radiation and diffuse sky radiation. It is a simple matter of trigonometry to convert the direct radiation into the component striking a surface at any given angle relative to the sun. This calculation depends on latitude, solar altitude and azimuth, collector orientation and tilt. The real problem is to separate out the diffuse radiation, which comes from the entire sky. The diffuse component ranges anywhere from 10% to 25% of the total, so it cannot be ignored.

Another factor that must be dealt with in these calculations is the energy reflected up from the ground and from buildings. Obviously, the steeper the tilt, the more significant this factor. Likewise, ground reflectance can vary considerably, from vegetation to white snow.

It is clear then that solar radiation data for heating design depends heavily on consideration of compass orientation, surface tilt, the ratio of diffuse to direct radiation, ground reflection, and how these all vary with time. It will also be obvious that the conclusions are still approximate due to inaccuracy of the data and variability of many factors. There are several methods of dealing with these factors, some more complicated than others. What follows is a somewhat simplified method which we feel gives reasonable accuracy within the limits of general discussion for New York City.

Insolation on various surfaces

The basis of our computations for actual solar insolation was Weather Bureau data on mean daily solar radiation on a horizontal surface for each month:

MONTHLY AVERAGE DAILY TOTAL RADIATION ON A HORIZONTAL SURFACE
btu/day /ft^2 New York, New York Lat. 40°46'N.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
540	791	1180	1426	1738	1994	1939	1606	1350	978	598	476

Source: LIU & JORDAN (see page d-5/19)

Data is recorded in Central Park which is probably reasonably representative for the entire city. Areas of clearer air would get better values, and heavily polluted or foggy areas less. There is, however, no actual data with which to make meaningful adjustments.

These data differ from the theoretical, clear data which are the basis for solar heat gain factors (SHGF's) in ASHRAE.

Our analysis takes into account, by averaging actual readings over time such factors as cloudiness, air pollution, and haze. Though this is a generalized consideration, it provides a much better basis for making longer term computations than is possible with the SHGF's.

The first step in computation for vertical walls at various orientations was to separate out the diffuse component of the total radiation received. Our source for this* provides curves for the ratio of total and diffuse radiation for times on either side of solar noon (plus & minus, 1/2 hour, 1½ hours, 2½ hours, 3½ hours, 4½ hours, 5½ hours, and 6½ hours). We calculated for the 16th day of each month (15th in Feb.) as a more representative day than the 21st day used by ASHRAE. We were able, by this means, to account for the changing length of days and, in a general way, for the sky conditions that create the diffuse component. This is at best an approximation, but is a reasonable one since it is considered valid for any location and is close to actual conditions. The diffuse component is a small part of the total, so a reasonably close approximation such as this won't seriously affect the overall accuracy.

The diffuse component is subtracted from the total to get the direct component on an hourly basis. By trigonometry, which takes into account the hour, angle, latitude, solar altitude, and solar azimuth, along with the tilt and orientation of the surface in question, we were able to arrive at the hourly values for direct solar insolation on various surfaces throughout the day. The diffuse component was treated as if sky radiation was uniform across the sky. For vertical walls, then, one-half of the sky is "visible" to the wall. Likewise, reflected radiation was treated as uniform from all directions. If half of the possible ground is assumed to be "visible," and the ground has a reflectivity of 0.2 (average value), one tenth of the total radiation is reflected on the wall.

These values for diffuse and reflected energy were added to the adjusted direct component values to give hourly values for various months and orientations. A simple summation for the day gives the expected average gain on vertical surfaces. These values were then plotted.

Computation for variously tilted, south-facing collectors was somewhat different. Using well-established ratios of diffuse to daily total radiation, based on the ratio of measured radiation to extra terrestrial radiation*, we were able to determine the direct component of the mean daily radiation. Through trigonometric conversion, which took into account the changing sun angle throughout the day and the collector tilt, we adjusted the direct component for variously tilted south-facing surfaces.

The diffuse component for the day was adjusted for the

reduced portion of the sky that the tilted surface could "see." The reflected component was likewise adjusted for the reduced portion of the ground affecting the collector. These were added to the adjusted direct component, giving mean daily insolation on the collector surfaces in question. The plots and tables of these data are the figures d-5/5 and d-5/6 of this section.

All of these values may, with reasonable confidence, be multiplied by the number of days in a given month to obtain a mean expectable solar insolation on the surface in question. Actual energy received can vary considerably, due to the extreme inconsistency of the weather not only day to day, but year to year. In any case, our computations yield data much more useable for solar energy collection analysis than the SHGF's.

Compiled Weather Data

The following sources have been used in the preparation of the tables which are included in this report:

1. Hourly solar radiation data for every hour of every day for the Central Park Station in New York City from December 1968, through November, 1973. The data is given in Langleys of radiation on a horizontal surface and includes both direct and diffuse radiation. No totals of any kind are included, either daily or monthly.

2. A paper called SUNSHINE AND CLOUDINESS AT SELECTED STATIONS IN THE UNITED STATES, ALASKA, HAWAII & PUERTO RICO which gives sunshine and cloudiness data for about 40 stations including New York City. Included for New York is a 54-year average of the number of hours, and the percentage of possible sunshine. It gives this information for each month of the year and an annual total. It also gives average cloudiness in numbers ranging from 0-10, for all the stations, and for New York City for 57 years previous to 1948. Averages are by month and include an annual average. Also for the 40 stations, including an average over 77 years in New York City previous to 1948, it gives the average number of clear, partly cloudy and cloudy days for each month of the year and an annual total.

3. CLIMATOLOGICAL DATA NATIONAL SUMMARY for January and July, 1971 and 1972. These are available for all months of the year, and contain: (a) Percentage of possible sunshine, showing the amounts of sunshine received in terms of

*Data are based on "Availability of Solar Energy for Flat-Plate Solar Heat Collectors", by Benjamin Y. H. Liu and Richard C. Jordan, in Low Temperature, Engineering Application of Solar Energy, by ASHRAE, New York, New York 1967 Our computations are somewhat simplified for their methods.

percentage of the total hours of sunshine possible during the month, shown in tabular form for stations and also as a national map; (b) the percentage of mean monthly sunshine showing a percentage of the mean number of hours of sunshine received, shown as a national map. Means are computed for the National Weather Service Stations having at least 10 years of record; (c) average daily values of solar radiation in Langleys showing monthly averages of daily total solar radiation both direct and diffuse in Langleys (cal. cm^{-2}) for all national weather service and selected cooperative stations which record these data shown as a national map. The analyses include adjustments required to bring station records to approximately the same level of calibration; (d) percentage of mean daily solar radiation showing the percentages of the mean based on at least five years of record during the period 1950-1960 and corrected to the International Pyrheliometer Scale of 1956, shown as a national map; (e) total radiation on a horizontal surface for each day of the given month, recorded at over 70 stations; (f) heating degree days for the month, and the cumulative total from the previous July.

4. Microfilm summaries for the period 1952 to 1965 comprising a chronological listing for cloudless days of total radiation on a horizontal surface in Langleys and percent of extra-terrestrial radiation reaching that surface. The microfilm also includes, by class intervals of Langleys, the frequency distribution of Langleys for all stations by month. New York City is one of the 23 stations. This tells how many days recorded a total radiation within any given interval of Langleys during a particular month.

5. Heating Degree Days for each month and the entire year of July 1972 to June 1973 in New York City. Also, the monthly and annual means of degree days, as averaged over many years.

6. Weekly Mean Values of Daily Total Solar and Sky Radiation in Langleys on a horizontal surface. Due to the 24-year period of record, the curve for New York City has averaged out to a smooth curve, cancelling out any irregularities that may have occurred in a particular year.

7. Tabular listing of mean monthly values for: total daily radiation on a horizontal surface (btu/day/sf); fraction of extra-terrestrial radiation transmitted through the atmosphere; ambient daytime temperature (as opposed to the 24-hour average temperature).

8. SOLAR HEAT GAIN FACTORS - Whole day totals for vertical surfaces at 16 different compass orientations and horizontal values account for direct and sky radiation, ground reflectance, and transmission losses through one layer of double strength glass. Units are btu/sf). Based on theoretical values for average cloudless days, taken from ASHRAE Handbook of Fundamentals.

9. COMPUTED SOLAR INSOLATION - Hourly and whole day totals for vertical surfaces at 8 compass orientations and horizontal. Based on actual Weather Bureau means for solar radiation in New York City. Units in btu/ft^2.

10. COMPUTED DAILY SOLAR INSOLATION - On south-facing surfaces at various tilts from the horizontal. Based on actual Weather Bureau means for solar radiation in New York City. Units in btu/ft^2.

	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
LANGLEYS	459	389	331	242	147	115	130	199	290	369	439	470
US CLIMATIC ATLAS BTU'S	1690	1440	1220	890	540	424	480	735	1070	1360	1590	1730
LIU & JORDAN BTU's	1939	1606	1350	978	598	476	540	791	1180	1426	1738	1994
COMPUTED BTU'S	1939	1606	1350	978	598	476	540	791	1180	1426	1738	1994
ASHRAE SHGF'S BTU'S	2148	1890	1496	1070	706	564	706	1092	1528	1924	2166	2242

FIGURE d-5/3: COMPARISON OF VALUES HORIZONTAL SURFACE INSOLATION

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
N	118	162	224	306	406	$\boxed{484}$	422	322	232	166	122	98
(EST) NNE	123	200	300	400	550	$\boxed{700}$	550	400	300	200	123	100
NE	127	225	422	654	813	$\boxed{894}$	821	656	416	226	132	103
ENE	265	439	691	911	1043	$\boxed{1108}$	1041	903	666	431	260	205
E	508	715	961	1115	1173	$\boxed{(1200)}$	1163	1090	920	694	504	430
ESE	828	1011	1182	$\boxed{(1218)}$	(1191)	1179	(1175)	(1188)	1131	971	315	748
SE	1174	1285	$\boxed{1318}$	1199	1068	1007	1047	1163	1266	1234	1151	1104
SSE	1490	$\boxed{1509}$	1376	1081	848	761	831	1049	1326	1454	1462	1430
S	$\boxed{(1630)}$	(1626)	(1384)	978	712	622	694	942	(1344)	(1566)	(1596)	(1482)
SSW	1490	$\boxed{1509}$	1376	1081	848	761	831	1049	1326	1454	1462	1430
SW	1174	1285	$\boxed{1318}$	1199	1068	1007	1047	1163	1266	1234	1151	1104
WSW	828	[illegible]	1182	$\boxed{(1218)}$	(1191)	1179	(1175)	(1188)	1131	971	815	748
W	508	715	961	1115	1173	$\boxed{(1200)}$	1163	1090	920	694	504	430
WNW	265	439	691	911	1043	$\boxed{1108}$	1041	903	666	431	260	205
NW	127	225	422	658	813	$\boxed{894}$	821	656	416	226	132	103
(EST) NNW	123	200	300	400	550	$\boxed{700}$	550	400	300	200	123	100
HOR	706	1092	1528	1924	2166	$\boxed{2242}$	2148	1890	1476	1070	706	564

Notes:
1. Numbers designated by bars: $\boxed{3714}$ indicate highest month of gain for given orientation.
2. Numbers designated by parentheses: (3714) indicate orientations of highest gain in given month.
Source:
ASHRAE, KOOLSHADE

FIGURE d-5/4:
SOLAR HEAT
GAIN FACTORS
WHOLE DAY TOTALS
40° N

TILT FROM HORIZONTAL	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
0°	1350	978	598	476	540	791	1180	1426	1738	1994	1939	1606
20°	1531	1202	806	691	754	981	1344	1436	1716	1971	1850	1719
40°	1562	1355	943	861	914	1155	1450	1470	1612	1730	1730	1574
50°			963	888	939							
60°	1400	1319	960	920	969	1160	1363	1268	1289	1394	1392	1294
70°			961	909	951							
90°	1033	1070	863	841	866	945	1032	830	769	755	805	855

UNITS IN BTU/SF /DAY, AT NEW YORK, NY, LATITUDE 40° 46' N.

FIGURE d-5/5: INSOLATION ON SOUTH-FACING SURFACES

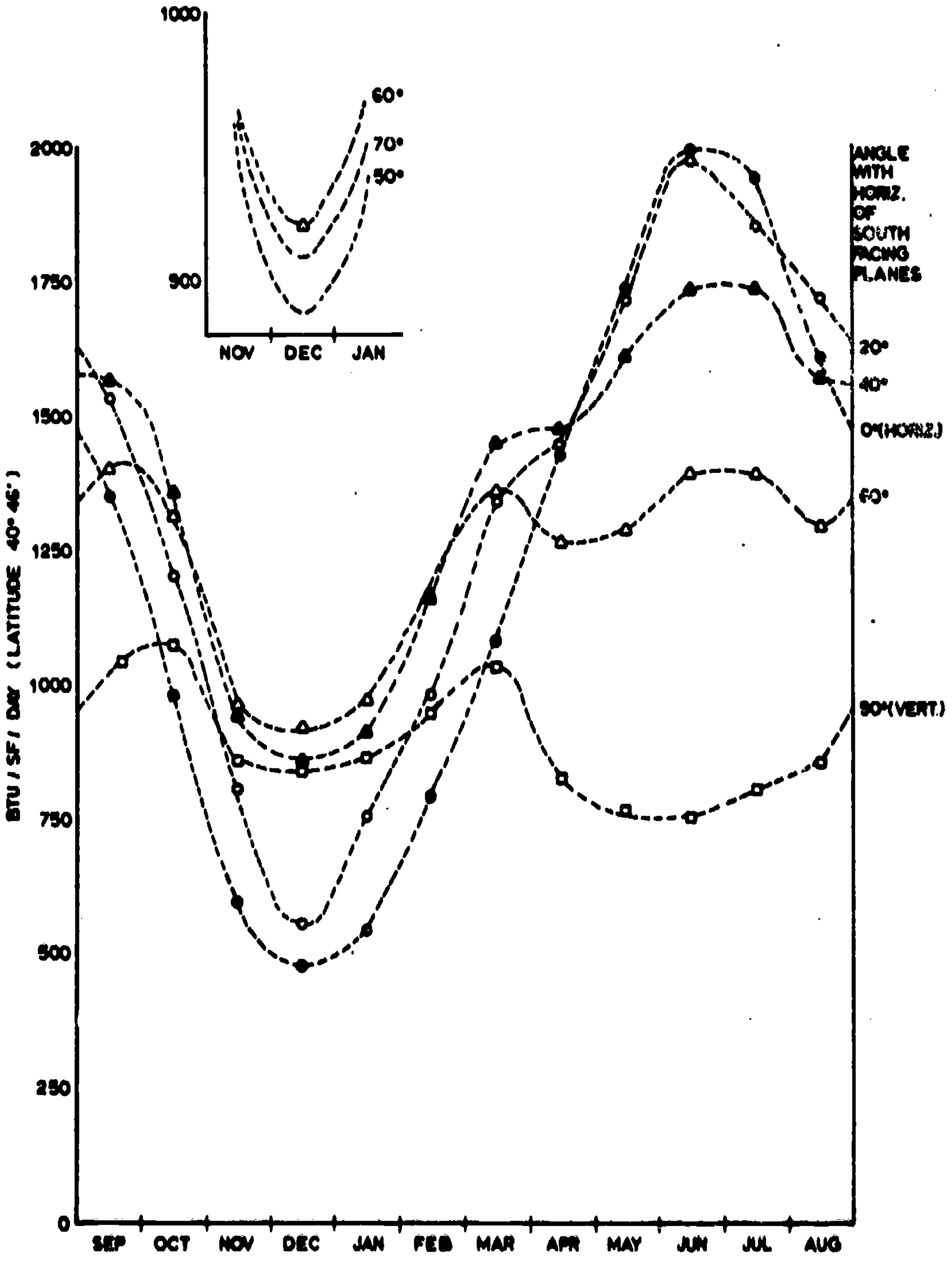


FIGURE d-5/6:
MEAN DAILY SOLAR
ENERGY IN
NEW YORK CITY

WALL ORIENTATION	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
N	374	280	202	152	178	248	336	430	548	628	618	540
NE	521	334	223	156	193	287	464	577	761	863	838	699
E	815	589	408	331	372	514	753	784	957	1041	1025	755
SE	992	857	671	623	645	785	956	885	930	969	919	970
S	1042	1022	838	818	828	954	1034	870	788	778	718	854
SW	992	857	671	623	645	785	956	885	930	969	919	970
W	815	589	408	331	372	514	753	784	957	1041	1025	755
NW	521	334	223	156	193	287	464	577	761	863	838	699

UNITS IN BTU/SF/DAY, AT NEW YORK, NY, LATITUDE 40° 46' N.

FIGURE d-5/7:
INSOLATION ON
VERTICAL WALLS

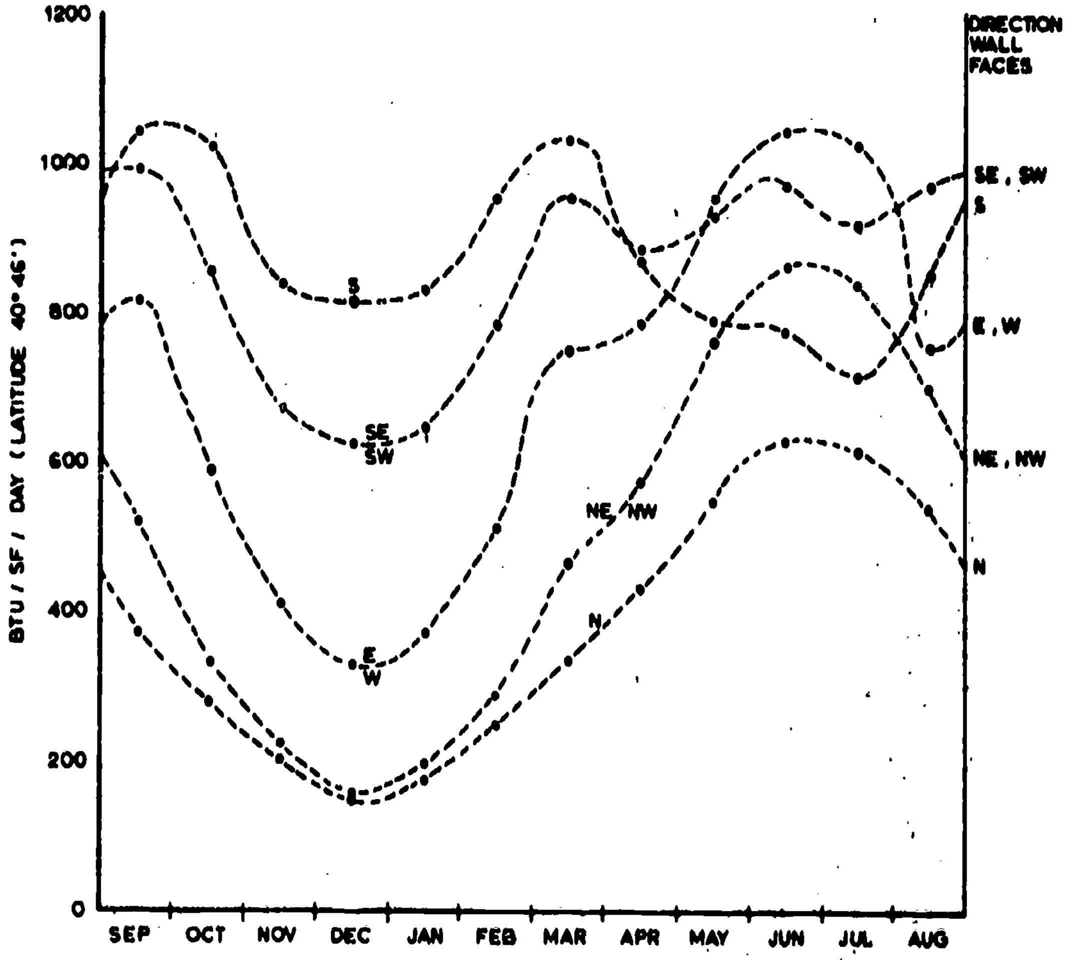


FIGURE d-5/8:
MEAN
DAILY SOLAR ENERGY
ON VERTICAL WALLS
IN NEW YORK CITY

d-6

prototypical proposals

6 ● LIGHTING

a) Provide adequate light levels for all tasks (see following summary of recommended light levels)

b) Avoid excessive light levels

c) Permit selective increase of light levels

d) Permit lighting to respond to varying educational formats

e) Avoid artificial lighting when natural light is available

f) Avoid providing artifical lighting to unused areas or spaces

g) Provide an upper limit to the power consumed by lighting systems

School Lighting Observations

The sub-reports document inconsistencies in classroom lighting, making it imperative that fundamental light requirements, light levels, light delivery systems and light system control methods be reexamined. We refer as background to the following.

1. Light level requirements have varied sharply and continue to do so, from code to code, from one year to the next and from country to country (sub-report h-2).

2. Actual light delivery to classrooms varies sharply from designed light levels, with light levels in some cases being appreciably higher, in others, appreciably lower, often in the same classroom (sub-report g-1).

3. An analysis of what takes place in the classroom in teaching-learning patterns points to the fact that hardly any classroom activities follow the typical classroom task on which general light levels have been determined, and the largest part of classroom activities requires considably less general light than is called for (sub-report i).

4. There is no correlation between higher light levels and more success in learning.

With these observations recorded, it became clear that other lighting potentialities and patterns should be examined, based on the criteria for learning previously recorded, and considering the statistic that about 65% of electrical usage results from lighting in the school.

MEANS OF PROVIDING AND CONTROLLING ARTIFICIAL LIGHTING

While it is felt that natural light should be used more widely and more effectively in schools, it is evident that artifical light will be required to supplement solar illumination if conditions a) and e) are to be met. This portion of the report deals primarily with the means of providing and controlling artifical lighting. The utilization of natural light is discussed in 'Solar Engergy' (section d-5) and 'Building Skin' (section d-3).

Lighting the Instructional Space

The most typical lighting situation in a school is that of the instructional space. Several possible solutions indicate a general approach to classroom lighting intended to conserve energy and, at the same time, provide an environment which is more responsive to the varying activities which may take place. The primary aspects of this approach are flexibility, responsiveness and ability to deliver light, where it is needed. There are certain areas in a room which can be assumed to have unique lighting requirements such as chalk and display boards and areas affected by natural light. There are also pieces of equipment and furniture such as sewing machines and reading carrels which have their special demands and solutions to lighting which are selfcontained, although not limited to any specific location within a room. There is, however, a large amount of activity which takes place away from these specific areas or objects and it may include lighting demands covering a wide range both of intensity and local positioning. As documented in 'Educational Tasks and Environmental Conditions' (sub-report i) 251 school tasks were identified, indicating the need for a flexible lighting system. The light levels assigned to the various tasks are summarized below.

Summary of Recommended Light Levels

<u>Ambient Light Level One (5-15 fc)</u>: Artificial illumination to provide sufficient light for general safety as well as sufficient ambient light for audio-visual presentations and non-visual tasks. Activities in this light range:

(a) Lectures and discussions (with additional light directed to teaching station, to chalkboard, to display when required)

(b) Audio-visual presentations

(c) Assemblies (with additional light when required)

(d) Cafeteria/dining (with additional light when used for other purposes)

(e) Corridors and stairs (with light concentrated at entry and egress)

(f) Shower and locker rooms

(g) Storage rooms

(h) Boiler and fan rooms (with additional light as required at equipment)

Ambient Light Level Two (15-30 fc): Artificial illumination for general use, adequate for reading and writing, but supplemented by additional task lighting where necessary. Activities in this light range:

(a) Teaching spaces for general purposes, including reading and writing tasks (with additional light directed to chalkboard, to display, when required)

(b) Library - general reading area (with additional light at tables and carrels when required)

(c) Gymnasium (with additional light for exhibitions/matches when required)

(d) Staff offices (with additional light at desks)

(e) Maintenance and Repair Shops (with additional light at machinery)

Ambient Light Level Three (30-50 fc): Artificial illumination for more precise tasks such as reading fine print, painting, model making, sewing, drafting. Additional lighting is indicated for most of these tasks. Activities in this light range:

(a) Library - audio-visual preparation area, record inspection, micro-files (with additional light within carrels, at desks and at equipment, where necessary)

(b) Art rooms for paintings, sculpture, arts and crafts (with additional task lighting where necessary)

(c) Drafting rooms (with additional light directly at drafting table)

(d) Shops (with additional light at machinery and equipment)

(e) Home Economics rooms (with additional light at kitchen equipment, at sewing machines)

(f) Typing rooms (with additional light at desks)

FOUR SYSTEMS FOR LIGHTING FLEXIBILITY

There are four basic ways that flexibility can be achieved. The following examples are intended to be illustrative rather than definitive. They are based on typical New York City classroom units of 750 sf with windows along one wall and chalk or display surfaces on the front and rear walls. The basic approaches to lighting indicated here can easily be modified to conform to other applications including larger, specialized classrooms or "open classrooms."

1. Refinement of Switching Patterns

Increase control options by refinement of switching patterns. This approach is basically upgrading conventional control patterns either by the addition of circuits permitting separate control of smaller areas of lighting or by using fixtures and controls which permit intermediate levels of output (multi-level or dimmed). In this system, the degree of flexibility is limited by the initial installation, that is, the arrangement of switching and fixture patterns is determined at the time of installation and is not easily altered afterwards.

Example A - Provide directed lighting on wall surfaces at front and rear of room for chalk and display surfaces (possibly single tube fluorescent fixtures with reflectors or low wattage high pressure sodium fixtures) and general illumination in center of room (conventional fluorescent fixtures with prismatic lenses). Switch each of the wall surface lighting groups independently and the general illumination fixtures with three circuits as indicated on the diagram:

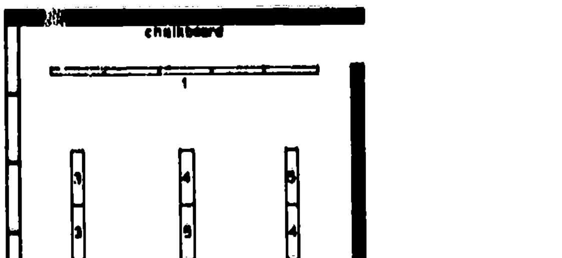


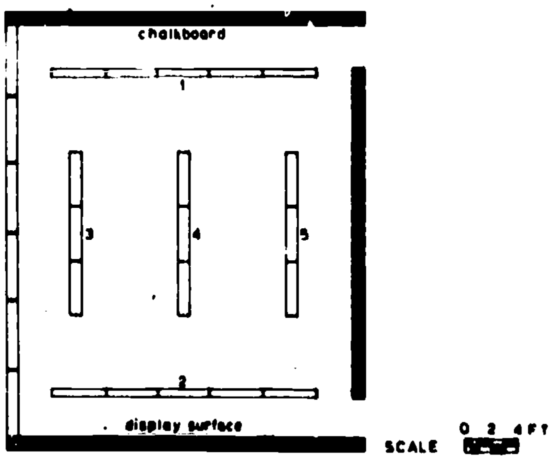
FIGURE d-6/1: FIXED FIXTURE POSITION WITH GRADUATED LIGHT LEVELS

The system provides three basic types of lighting, that is, vertical surface illumination, general illumination for the interior zone of the room, and

supplementary general illumination for the zone where natural light is generally available. The interior zone is multi-leveled with circuit 5 providing a graduated increase in lighting as the distance from the windows increases.

Example B - A variation on this first system is one which the control function is carried out by dimming devices rather than by on-off switches. In this situation, however, the switching pattern is slightly different:

FIGURE d-6/2: FIXED FIXTURE POSITION WITH DIMMERS

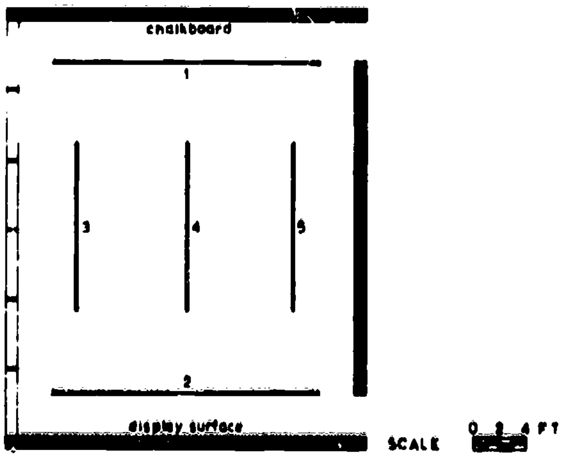


2. Adjustable Fixture Positions

The second basic degree of flexibility comes through the use of adjustable fixture positions. This can be either some form of conventional light track or a series of outlets and clip-on fixtures. In this case, as in the previous one, the control functions are fixed at the time of initial installation.

Example C - Provide five light tracks with individual dimmer control as indicated:

FIGURE d-6/3: TRACKS WITH INDIVIDUAL DIMMERS



With this arrangement, lighting can be arranged in response to the unique requirements of each wall surace, as well as to variations within the central area.

Example D - Provide a grid of outlets in the ceiling with provisions for attaching clip-on fixtures. This can be accomplished with a pipe grid serving both as conduit and mounting support:

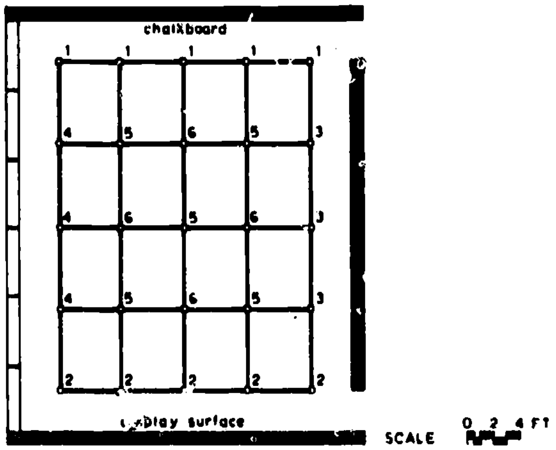


FIGURE d-6/4:
GRID WITH FIXTURE
TYPE OPTIONS

The advantage of this system as opposed to a track system is that any selfcontained fixture that can be hung and plugged into a conventional outlet, can be utilized permitting great freedom in future fixture selection.

3. Switch at Fixture

Placement of the switch at the fixture rather than at a remote location on the wall offers the possibility of individual control without increasing the amount of wiring, in fact, in many cases reducing it. The problem becomes one of operating the switches. One solution is a simple mechanical extension, such as a pull chain, to operate each switch within the context of a typical instructional space. Since this method is apt to present considerable problems an alternative method of mechanical or electronic relays ought to be considered. These relays may be activated by electrical signals which are carried on wires, or by light or sonic signals which are air-borne and sent directly to the relay's receiver. The advantage of this second method is that there is no limiting wiring pattern. The disadvantage is that a control device must be provided. A wired system with a number of channels can provide a series of options which can be varied as needs change. This wired system may utilize individual channels which can be selected at the fixture or a single path with multiplexed signals discussed in 'Controls' (section d-11). The basic

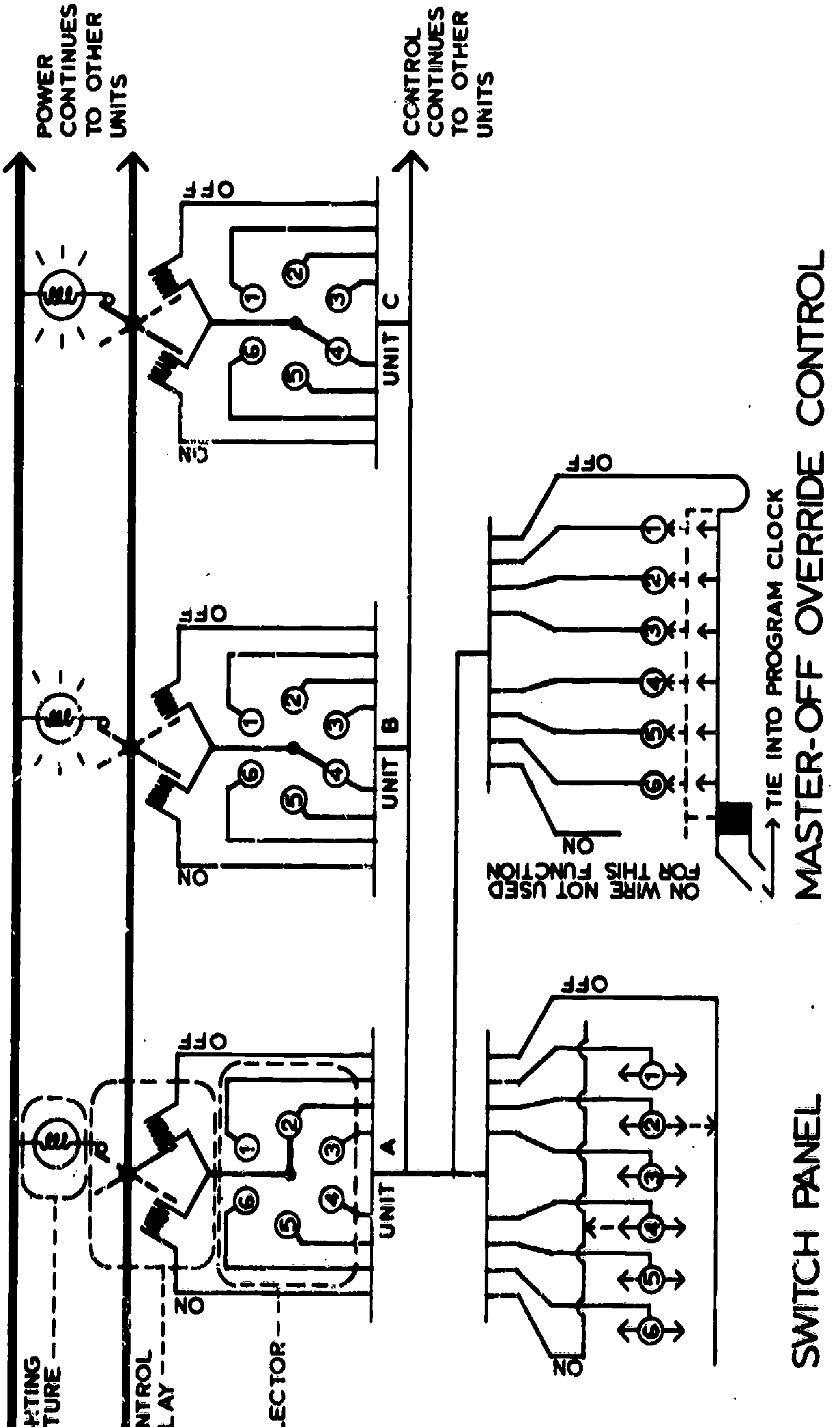


FIGURE d-6/5:
LOW VOLTAGE
LIGHTING CONTROL

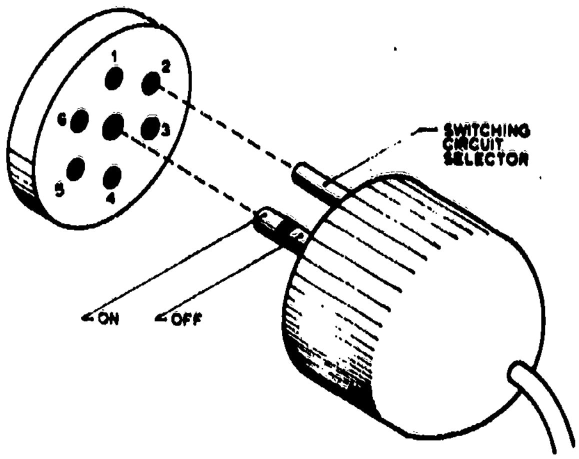
control pattern in a six-channel "hard wired" system is diagrammed in figure d-6/5. The arrangement of fixtures shown in 'Example A' coupled with this switching system would yield the following:

> Example E - Provide fixtures as indicated in 'Example A' except that switching will be accomplished by relays at each fixture control by a six-channel signal system. Fixtures can be adjusted to respond to signals on any one of the six channels. The advantage of a system like this is that if a teacher or student wants to utilize the lighting to augment some aspect of the teaching situation which was not anticipated at the time of design it is possible to do this simply by changing settings on the fixtures. There is no need to alter any of the built-in equipment. With this system it would be possible to split the lighting on the chalkboard onto two separate circuits, so that a lecturer could draw attention to one area or the other as a class progressed.

4. Adjustable Fixture Position and Switching Pattern

Final degree of flexibility can be achieved by a system of adjustable fixture position and switching pattern. This could be achieved utilizing either track or clip-on lighting with a second plug to tie into a control circuit. In the case of the multi-wire system, this could either be an eight-pin coded plug or a two-prong plug going into a receptacle with one center and six perimeter holes, the center hole being coaxial and containing the on and off leads and the six outer holes being the means for tying into the one of six circuits desired.

FIGURE d-6/6:
CIRCUIT
SELECTING PLUG



With this approach, the arrangement of fixtures and patterns of control could be varied widely as the requirements changed. This is of particular importance in a situation such as an open classroom where there is a large area with few fixed components and where the use of space may change

considerably from week to week.

Promoting Operation of Energy Conserving Options: The availability of lower energy options will not in itself ensure the use of these options. Several techniques may be used to further this end:

Education

There are a number of obvious means for educating occupants to the use and importance of energy saving features of a space. The first is by permanently installed plaques at the controls describing exactly what each control does and the energy implications of operating that control. Second is an operation manual which would be given to both teachers and students and which might become part of a larger educational program relating to environmental and resource evaluation. A third possibility is the creation of a short film which could be shown at an assembly at the beginning of each school year. A fourth approach is the encouragement of various student activities in which light use is also tied into an appreciation of the visual quality of space. The students can, for example, assume the role of stage lighting crews to keep a room's lighting related to the changing teaching and learning situations.

Establishment of Clear Cause and Effect Relationships

The typical switch arrangement observed in existing schools is that when two circuits do exist for classroom lighting, the switches are ganged together at a single cover plate. With this arrangement, the tendency observed is to operate both switches together often with a single hand motion without considering the option of only using only half the lights even when that would be more than adequate. In order to reduce this problem, locate switches near the fixtures they control. This will serve the double role of preventing the simultaneous operation of switches and also point out the function that operation of specific switches serves.

Automation

There are two serious areas of concern regarding the use of automated controls for building environmental functions. First, in order to provide automation there is a tendency to simplify areas of control which in turn reduces responsiveness to local conditions. Second, large scale automation can create a feeling of helplessness in the occupants regarding their ability to control their own environment.

With these things in mind, school classrooms seem ideally suited to two types of automatic light control. One is the use of photo-sensitive cells restricting the operation of fixtures near window areas. The other is programmed shutdown of all but emergency classroom lighting at the end of each class period.

The photo cell control can operate in either of two ways. If the control is by means of dimmers, the artificial levels can be gradually and continually modulated as natural light

levels vary. If the control is by on-off switch, the photo cell can activate a positive lock-out which would take effect at the end of each period. In this way, students would not be distracted by having lights go out during classes, but if the light levels had increased while one class was in progress, the lights would remain off during the next period. If, during that next period, the outside light level were to drop again, the over-ride restriction would be removed. However, the lights would not turn on until someone activated a switch. An automatic shutdown at the end of each period operating through a low voltage switching system like that diagrammed in figure d-6/5 would have two substantial benefits. First, it would prevent lights from being left on if the classroom were not in use for the subsequent period. Second, since it operates by throwing each relayed switch to the off position when the room is next used it is necessary to reactivate each circuit individually. Thus, if one class requires a very high light level and the next class a low level, the tendency of using the higher level for both due to the previous setting will be avoided.

POTENTIAL SAVINGS IN CLASSROOM LIGHTING

It is difficult to predict exact savings that will be achieved in a system that relies at least in part on human participation with the system. Observations in a number of schools indicate that even with a minimum number of options, systems behave quite differently from predictions. Several assumptions may, however, prove valuable in anticipating the magnitude of the effect of installing any of the systems discussed.

1. Total load for lighting in typical 750 sf classroom as designed today (including tubes and ballast) 1400 to 1700 watts.

2. Typical operating pattern
   a) All light on whenever room is occupied.

   b) Room is occupied by teacher alone or teacher with one or two pupils typically about one-half period per day, average.

   c) The average classroom is vacant about 1½ periods per day.

   d) Lights are left on in vacant classrooms about 50% of the time.

   e) In classrooms where the perimeter lights are separately switched, they are almost invariably turned on whenever the room is in use. NOTE: An exception to this was observed in a high school in which the custodian had overridden the local controls and rendered the perimeter lights inoperative. At about 11:00 AM in mid-December with a heavy overcast (intermittent snow), a series of rooms with southeast exposures

were observed. With shades partially drawn, light levels on desk tops ranged from 65 footcandles on those closest to the windows (where lights were inoperative) to 8 footcandles farthest from the windows. The significant factor in this observation is that even with dense clouds, natural light was still sufficient to illuminate about one-third of each classroom observed.

Classroom Lighting Schedule

f) Schedules vary somewhat from school to school, however, the following could be taken as representative.

15 minute morning homeroom
eight/45 minute periods (40 minutes of class, 5 minutes between classes)
15 minute afternoon homeroom

This excludes for the time being any after-school use. The following quantities should be taken as typical averages. The classroom is in use 6½ hours (390 minutes) per day for regular school use.

Breaks between classes account for 45 minutes per day. By automatically shutting off lighting 1½ minutes after the end of one class and assuming that the present pattern of keeping the students outside the room until about one minute before the next period, a total of 22 ½ minutes per day of minimum emergency light level could be obtained. Assume this becomes 18 minutes due to some earlier start-up than predicted. In a 180-day year at a load reduction of 1400 watts this yields a savings of about 75 kwh/yr/classroom.

For 20 minutes per day the classroom is used by one to four people. The use of only the required lighting would reduce the load by about 900 w yielding an annual savings of about 55 kwh/yr.

For 60 minutes per day the room is vacant. About half of this time the lights have been observed to be on. If these lights were turned out lowering the load by 1500 w for 30 minutes per day average, the savings would be 135 kwh/yr.

For 260 minutes per day the room is used with approximately its normal capacity. Oberservation and research has indicated that for at least three-quarters of the tasks that take place in classrooms, the lighting input could be thirty percent of what is currently provided resulting in a reduction of more than 50 percent of total. If the various stimuli to reduce levels are half effective, yielding a twenty-five percent reduction, a 295 kwh/yr saving would result.

If a system is used which adapts itself to respond to natural light, a one-third reduction for 200 minutes per day could be realized, or an annual savings of about 300

kwh if applied directly to current practices, or about 190 kwh if applied to a system with reduced initial loads.

These savings total 740 kwh/yr. While the potential savings listed above are not cumulative, it is reasonable to project a savings of anywhere from 350 to 650 kwh/yr per classroom within the regular school hour use plus an additional 3 to 5 kwh for each ten hours of after-school activities for which the classroom was used. These savings are above current savings achieved during the past winter. At current electric rates, (approximately 7¢ kwh) this represents a savings of \$25 to \$45 per classroom/per year, exclusive of after school hours.

The hypothetical classroom would use 1550 kwh/yr if normal lighting were installed and the projected patterns followed. These projected savings are based on a relatively low usage pattern. In a series of studies, classroom lighting was found to consume about two-thirds of all electricity in a school of which half went into classroom lighting. For example, a 175,000 sf intermediate school has about 70 classrooms. At the rate of 1550 kwh/yr/room this would be a classroom lighting use of 108,500 kwh/yr or a total electric usage for the school of 325,500 kwh/yr. This converts to 1860 kwh/msf/yr which compares to the average for all NYC schools of 3861 kwh/msf/yr for the 71-72 year. This is probably fairly accurate because it does not reflect any after-school, weekend or summer activities and it is compared to a use rate existing before any public awareness of the energy situation. Still, if the estimate is low, the potential energy savings will just be greater.

Summary of Findings

Classrooms

1. Provide approximately 40 percent of the classrooms with increased switch circuiting to permit both localization of light delivery and modulation of level by "checkerboard" light patterns from 15 to 60 footcandles.

2. Provide approximately 40 percent of the classrooms with multi-level fixutres to permit reducing light levels throughout entire classroom to those actually required for activities taking place.

3. Provide each of the remaining classrooms with either a conventional track-light system, a system of fixed lights with adjustable switching patterns or a system where both fixtures and switching are adjustable, the last two being accomplished either by multi-wire low voltage or multiplexed control systems. In addition, provide some of these rooms with automated switching on an experimental basis. This might include photo-sensitive controls for perimeter zones and timed shutdown of lights based on end of period signals.

4. Provide selected rooms with a series of work stations with integral lighting to permit a low general light level to be maintained while still satisfying requirements for those students performing demanding visual tasks.

Special Purpose Rooms (Gymnasium, Cafeteria, Auditorium, etc.)

1. Re-evaluate the scheduling and use patterns expected in each area of the specific building in question and provide appropriate light delivery system with particular emphasis on ability to deactivate areas or reduce levels when services are not needed. For example, in keeping with current use practices, provide two light environments in an auditorium -- one for assembly, one for study hall use. In a cafeteria provide lighting conditions suitable for dining, maintenance and study hall use. Controls should permit selective lighting of individual areas within cafeteria for times when groups are using small portions of the space.

2. Provide automated shutdown of light systems when it is anticipated that occupants will not utilize systems and when scheduling can be easily predicted.

Offices

1. Provide ambient light levels of 15-20 footcandles and specific illumination at work stations. Note: the ambient light may be provided by the same fixtures which provide the task light permitting great flexibility in the space use.

Corridors

1. Provide light levels of 5-10 footcandles in corridors.

2. Use light reflecting wall surfaces.

3. Where alcoves or short corridors occur, provide supplementary illumination to prevent shadowed pockets.

Note: Provide service capacity for possible future augmentation of lighting systems to current standards.

d-7

prototypical proposals

7 ● HEATING

a) Provide adequate minimum temperatures for all times when school is occupied, varying temperatures according to activity.

b) Avoid excessively high temperatures.

c) Permit selective heating of portions of school during partial occupancy.

d) Avoid redundant heating when solar or internal gain will maintain adequate temperature without mechanical support.

There are a number of sources of heat which result from the normal activities which take place within a building. These include heat released by occupants and heat produced by the use of any electrical equipment such as lights, motors, appliances, etc. In one sense, this is free heat since the expenditure of energy which generates this heat is required to operate the building in any case. It is important to remember, however, that the devices which are producing this heat are not specifically designed for that use. The heat which results from required lighting reduces the load on a building's heating plant but the increase of light levels far beyond needs in order to provide all heating from this source results in great increases in overall fuel use. This is due to the following factors. First, light fixtures are not designed as heaters and therefore frequently do not deliver heat where, when or in the exact quantities needed. Second, the use of electricity to produce heat is inherently inefficient (see discussion of conversion of fuel to heat which follows). For example, if lighting is the only source of heat, heat required at window areas where heat loss is greatest will necessitate the use of large numbers of fixtures at these areas. These areas, though, generally have adequate natural light so, for lighting purposes, the fixtures are unnecessary. These fixtures will produce about one btu of heat for every four btu of energy consumed at

the generator and this heat will probably not be delivered to where it is actually needed. A conventional heating system, however, will deliver one btu for every one and a half or two btu input and will deliver heat to where it's needed. The introduction of lighting above required levels in order to supply all required space heating should be avoided.

A second major source of heat is solar radiation. A full description of its heating potential is included in section d-5, Solar Energy. This approach should definitely be considered as a means for reducing the fuel required for space heating.

In most cases, the heat sources described above are not adequate to provide for the total needs of a building. When this occurs, additional input will be required from a heating plant. Where systems are controlled by local, interior thermostats, the heating system will deliver only the heat that is required to make up the difference between the demand and the available "free" sources. The provision of the make-up heat is the subject of this section.

Conversion of Fuel to Heat

Most processes in which fuel is used to generate energy start with the production of heat. Where the final form of energy desired is also heat, it is generally more efficient to use the original heat directly rather than to convert it to some other form of energy such as electricity. The major difficulty with the direct use of heat is that it is relatively inefficient to transport energy as heat for any long distance. For space heating, the basic available heat sources are locally generated heat, generally carried in steam or hot water; centrally generated heat, generally district steam; and electricity. The first two are direct heat sources and range from about 50 percent to about 80 percent efficient. Electrical generation uses heat to create steam which in turn drives the generators' turbines. The generation and distribution processes result in a delivered efficiency for electricity of about 25 percent. Because of this low return of heat energy compared to fuel input, electric heating should be avoided except where the direct use of heat energy is not feasible.

Total or Selective Energy

A total or selective energy system is one in which electricity is generated locally and the heat which is normally wasted is used for heating, domestic hot water and absorption cooling. In buildings where size and demand make this approach feasible, it should be evaluated for the specific instance on the basis of fuel use and economic factors.

Heat Recovery

In smaller projects which cannot support consideration of total or selective energy, other forms of utilizing what is normally waste heat should be evaluated. These include the use of heat exchangers to pre-heat incoming air, or supply radiant panels, and also heat pumps to take heat from one

area where cooling may be required and tranfer it to a zone with a heating demand.

Design Conditions

It is recommended that 5° F outside design temperature be used to permit rapid morning heat-up although ASHRAE 99% data indicate an 11° F outside design temperature. The indoor temperature of the school should be based upon the expected usage of a particular space. Thus, classrooms with relatively minor activity should maintain a comfort temperature of 68° F. Thermostats for individual room control should be set at 65° F, that is 3° F lower than maintained temperature to allow for temperature override due to lack of equipment response as well as additional heating that may be provided by direct sunlight. A further consideration that must be taken into account in the design of the equipment and in calculating the heat losses is the "exposure" factor. This is related to building location, building construction, prevailing wind direction and degree of exterior exposure.

Distribution System

Heating only. Use low pressure steam systems with vacuum return. The advantage of the low pressure steam system is that it allows rapid warm-up of school buildings after shut-down and avoids freeze-up during shut-downs. Low pressure steam minimizes operational supervision problems. Steam pressures in excess of 15 lbs necessitate operation of plant with licensed engineers and may further increase operational servicing problems. Steam heating systems should not be utilized where both heating and cooling of entire schools is contemplated, since a duplication of the distribution system would be required.

Heating with air-conditioning. If a building is to be air-conditioned as well as heated, then it is recommended that whatever the energy carrying medium utilized, it be adaptable to both heating and cooling use; thus, where air conditioning is required, the combination of hot or chilled water through the same piping system or heated or cooled air should be used.

Water provides a desirable medium because of its high density. Air with the equivalent heat-carrying capacity as water occupies a volume much greater than that required for water. Large schools with air distribution systems require the use of multiple equipment rooms because of the large duct sizes and transmission losses inherent in extended distribution runs.

Zoning. Sectionalizing portions of the school based on function is essential for energy conservation and permits selective heating of required spaces without the necessity of operating the entire building plant. Because of ventilation requirements for large places of assembly, auditoriums and gymnasiums as well as dining facilities should be designed using indirect heating systems, i.e., air supply

units containing heating coils (and possibly cooling coils) with fans distributing the air to the respective spaces. In high spaces provide for air distribution patterns that prevent stratification.

Air Distribution. Low velocity or medium velocity equipment should be designed and utilized in preference to high pressure air distribution systems which consume more energy. Avoid dual duct systems in which temperatures are modulated by mixing chilled and heated air. Systems should deliver one or the other and respond to temperature requirements by varying volume.

System Insulation. In addition to the insulation in the skin of the building, the insulation of the heat delivery system is important to avoid loss of heat to spaces that do not require the heat.

Boilers

It is important in the selection of boilers to size the units to follow the load profile for the schools through the heating season as closely as possible. The following factors should be given consideration in sizing boilers:

1. Boiler efficiency on the order of 80 percent for loads down to 50 percent of input rating is common. Below 50 percent of input rating boiler efficiency drops rapidly.

2. In New York City schools, the outside air ventilating load constitutes, at design conditions, between 60 and 75 percent of the total heating load, based on current local design practices of providing 15 cfm per occupant of outside air in classroom situations.

3. In studies carried out at Ohio State Engineering Experiment Station, it has been found that the ratio of actual calculated heat load to designed heat load is below 40 percent, approximately 94 percent of the time for a one year period as measured at a single school. Therefore, it is recommended that boilers be split into incremental (modular) units utilizing individually sized multiple cast iron heat exchangers in units of 10 to 20 percent of design load for both #2 and #4 oil. In schools utilizing #6 oil, a minimum of three boilers, two sized at 40 percent of design load and one boiler of 20 percent design load should be utilized. Any boiler sized at 40 percent of design load should be adequate to supply all of the heating energy required the largest part of the heating season. These boilers would be rotated in usage. During a substantial portion of the heating year, the 20 percent boiler is adequate for the full heating load. In the event of one of the boilers failing, the second 40 percent boiler can be put on the line. In the event of both of the 40 percent of design load size boilers failing simultaneously, the 20 percent of full load design boiler could heat the school with the outside air shut off during the repair period, in all but the most severe weather.

Oil-Burning Equipment

<u>No. 6 Oil</u>. It is expected that #6 oil will be the prime heating fuel for most future school buildings. On the basis of current operating experience, the use of forced draft rotary cup burners is recommended. These units provide good optimum performance and, because of the simplicity of design, are apt to be operated close to this optimum. In addition, they have relatively low ancillary electrical loads which results in an indirect fuel savings. The use of pre-set air intakes for low range partial loading should be explored.

The exact performance characteristics of rotary cup and air atomizer burners in actual operating conditions are not currently available. It is recommended that National Bureau of Standards monitor and record this information in a school specially equipped for this study with one burner of each type. The results of this test should be available in time to affect the final decision in the prototype building.

<u>No. 2 and No. 4 Oil</u>. In buildings where the heating load is less than 5,000,000 btuh and modular boilers are utilized, medium pressure air atomization burners should be considered.

<u>Ultrasonic Oil-Water Mixing</u>. It is recommended that National Bureau of Standards run laboratory tests to determine the effect of the Cottell or similar process on fuel consumption. These tests should be carried out during Phase II which will permit the use of the device in the prototype building if the results indicate that its installation is merited.

Terminals

Terminal devices herein are defined as the device by which energy is transmitted into the area for either heating and/or cooling.

<u>Typical classrooms</u>. Where steam or hot water is the medium for transferring the heat from the energy generating plant into the space, use radiators or convectors individually controlled. For both heating and air-conditioning utilize fan coil units.

<u>Kindergarten and Pre-Kindergarten</u>. Consider radiant floor unless floor is carpeted. Use air-floor system with heated air discharged under windows. This system provides both warm radiant floors and prevents cold drafts at window-walls. An alternative to this is the use of unit ventilators at the exterior wall.

<u>Offices and other administrative areas</u>. Use convectors or finned-tube radiation for heating. Utilize fan coil units when cooling is provided.

<u>Gymnasiums and Auditoriums</u>. Air distribution to ventilate and heat gymnasium and auditorium spaces generally is accomplished by means of ductwork, which may be located overhead or in the crawlspace underneath the floors of the re-

spective spaces. Air may be distributed through grilles, registers, and/or overhead air diffusers. Air is returned to the fan rooms utilizing ductwork connected to a point source return, such as single or multiple registers or grilles. Provided a proper uniform distribution method is installed, the location of the air returns is relatively unimportant. For design criteria, it is recommended that ASHRAE Standards be followed.

Attention must be given to the question of stratification. Air movement patterns must be established to assure that heated air does not layer at the top of these spaces, particularly when there is a major ventilation load drawing off this heated air.

Heating Systems Controls

The idealized control system follows the energy load profile dictated by outside temperature conditions as well as the internal load variations of each space.

Classroom temperature control. Heating elements within classrooms, whether steam or hot water, should be controlled by individually operated control valves modulated from a thermostat within each classroom. Based on observations in existing schools, these thermostats are frequently subjected to tampering. They are also affected by local thermal conditions. It is therefore recommended that in selected rooms they be placed just inside a return air grille where they will receive a more consistent sample of room air and will be protected from the room occupants. The control system may be either pneumatically or electrically actuated. For large schools, pneumatic control systems are recommended.

Gymnasium and Auditorium Temperature Control. These so-called indirect heating units consisting of air supply fans, heating coils for preheating and reheating the air introduced into the space, together with possible return air fans which either return the air or exhaust it as needed, should be controlled from a master, sub-master type discharge controller regulating the steam or hot water valves in the heating coil section of the air supply system. Control systems must be so designed as to permit keeping fresh air dampers closed during warm-up and during light occupancy periods. The damper arrangement should be such as to keep the exhaust air damper closed until the mixed air temperature exceeds 75 degrees. The sequencing of the controls must first shut off the heating energy supply prior to opening in sequence outside air dampers and exhaust dampers.

Where practical, consideration should be given to economizer cycle operation during mild weather and for exhaust air, and to energy recapture through the utilization of air to air, air to water heat exchangers.

Heating Plant Operation

Provide as part of the maintenance offices, a plan and document room, with sets of mechanical (and other) drawings on

cloth. Provide a clear operating manual in non-professional language. Mark and identify each valve and control point clearly and permanently. Mount permanent, clearly printed instructions on the use and maintenance of equipment near the equipment.

Summary of Findings

Standards

1. Outside design temperature 5° F

2. Classroom design temperature 68° F (set at 65° F)

3. Administrative area design temperature 68° F

4. Gymnasium design temperature 65° F and 70° F based on type of activities taking place

5. Storage area design temperature 50° F

6. Other spaces as called for in latest School Design Planning Manual

7. Exposure factors to be determined after site selection

Distribution System (predicated on heating only with no provision for additional air-conditioning)

1. Utilize low pressure steam with vacuum return.

2. Sectionalize building and system to permit selective heating of spaces including small groups of classrooms, auditorium, and gymnasium during after-school hours.

3. Use dual level thermostats (similar to day/night thermostat using automatic reset with override feature) to allow two levels of settings and system off.

4. Locate controls centrally to facilitate the selective use of the system.

Boiler

1. Except as noted below, #6 oil is recommended. Provide a minimum of three boilers, two of which will be sized at 40 percent design load, the third at 20 percent.

2. If design heating load is less than 5,000,000 btuh, individually-fired multiple cast iron heat exchangers (modular boilers) in units of 10-20 percent of design load utilizing #2 and #4 oil should be considered.

Oil Burning Equipment

1. Forced draft rotary cup type burners are recommended for all grades of fuel oil except as noted in the following.

2. If #2 and #4 oil is to be used with modular boilers, consider air atomization medium pressure type burners.

Note: Conventional practice with rotary cup burners is to use variable dampers to modulate combustion air intake at partial operating levels. At lower levels this system is difficult to control accurately. Investigate whether a burner with a finite number of settings (e.g. four) with corresponding adjustable combustion air ports would perform better at lower fuel rates. The installation would require tuning after installation to set the fixed openings.

3. It is recommended that as part of Phase II, National Bureau of Standards evaluate a device such as the Cottell system which introduces water into the fuel-oil by ultrasonic or other means.

Terminals

1. Typical classrooms: Provide perimeter radiation with individual room control. In selected classrooms, locate temperature sensors in exhaust air ducts and place controls in secure location (possibly behind grille). This will tend to prevent tampering and false readings resulting from local conditions.

2. Kindergarten and pre-kindergarten classrooms (where programmed): Consider air floor radiant slab with hot air discharge at perimeter wall to counter cold-wall effects.

3. Gymnasium, Auditorium: Provide heated air system with 100 percent recirculation capability for warm-up and use with limited occupancy. Where more than 25 percent of the air is exhausted, analyze heat recovery devices. These may be heat exchanger wheels, air to water to air loops or air to air counter-flow exchangers.

d-8

prototypical proposals

8● COOLING

a) Utilize systems which can discharge excessive internal heat to the outside by non-mechanical means whenever inside temperatures are higher than outside.

b) Where mechanical refrigeration is used to provide space cooling, provide systems which are supplements to natural cooling systems and which will be deactivated whenever natural cooling can be achieved.

Interior spaces must be cooled when build up of heat from interior sources occurs faster than the loss to the outside or when heat flows from the outside to the inside because the outside temperature is greater than the inside. In the first case, the ability to "dump" heat to the outside by non-mechanical means will often be sufficient to maintain acceptable temperatures. This requires that the outside temperature be no higher than the inside. (Heat will only flow from bodies with higher to bodies with lower temperature). If it is desired to lower the inside temperature below the outside temperature, mechanical cooling must be provided. An additional aspect related to ambient cooling is local cooling resulting from surface evaporation on the occupants' skin resulting from air movement.

Outside Air Cooling

The basic aim of non-mechanical cooling is to prevent inside temperatures from rising much above outside temperatures. If there is a tendency for internal heat gains to raise inside temperatures above outside, conduction will generally be unsatisfactory as a method for rejecting this excess heat. This is due to the fact that the rate of conducted loss through a given material is a function of the temperature differential which, when overheating is a problem, is apt to be quite small. Instead, the actual exchange of inside and outside air will permit movement of large amounts of heat. In order for the exchange to take place, some force must induce the air to move. Two basic natural conditions -- wind pressure and gravity -- will in most cases act to this end.

Wind Pressure. There is almost always some outside air movement which will cause different exposures of a building to experience different air pressures. If a space has openings to two exposures, air will flow from the higher pressure through the space and out through the opening at the lower pressure. The rate of this flow can be determined from the equation

$$Q = EAV$$ (see sub-report g-2)

(One of the exposures can be a roof as well as a wall surface. It is also possible to have different exposures on a single wall surface resulting from the treatment of openings.)

Gravity. Hot air weighs less than cooler air and therefore tends to rise in the presence of cooler air. When inside temperatures are higher than outside, an opening at the top and the bottom of the space will permit the hot air to rise and escape from the higher opening causing cold air to be drawn in through the bottom. The force acting to cause this flow is a function of the temperature differential and height between the openings. Since it is desirable to have air change taking place at the smallest temperature differential, it is desirable to increase the height between the openings. The utilization of height to promote air movement due to temperature differential is referred to as the "stack effect". The actual quantitites of air movement that can be expected can be determined from the equation

$$Q = 9.4A\,h(t_i - t_o)$$ See 'Analysis of Observed Ventilation Performance' (sub-report g-2)

It is also possible to increase the temperature differential without adding unwanted heat into the interior environment. This is done by heating the air after it leaves the occupied space but before it is freed into the outside environment. This is the basic principle behind the summer mode of the thermo-siphoning wall panel described in 'Building Skin' (section d-3).

Evaporative Cooling

When moisture evaporates, there is sensible cooling resulting from the change of sensible to latent heat in the process. If this is surface moisture on the skin, a relatively small actual heat change can result in a large difference in comfort due to the fact that the temperature drop occurs right at the occupant. Air movement will promote evaporation by preventing moisture concentrations from building up around each occupant. This air movement can be totally internal as induced by local fans, or can result from air passing through a space. Circulating inside air is advantageous when outside temperatures are higher than inside. Of course at some point, the concentration of moisture in the air builds to a point that evaporation will not occur. However, the normal minimum requirements for outside air

will prevent this from occurring.

At times when outside temperatures are lower than inside, the conversion of sensible to latent heat carried by evaporated moisture will increase the effectiveness of the air as a medium for removing heat from the environment.

Mechanical Cooling

The basis of the design of air-conditioned New York City schools shall be as suggested by ASHRAE Handbook of Fundamentals 1972, Chapter 33, Table 1, 5 percent data. Outdoor temperature 88° F dry bulb, 75° F wet bulb. Indoor 78° F dry bulb, 60 percent relative humidity. (The 5 percent data shall indicate in New York City that of the 3,000 hours of cooling required, 150 hours will exceed the conditions stated for limited periods of time). The selection of indoor conditions is based on a fair degree of comfort. It is recommended that all fully air-conditioned schools utilize the same piping system for both heating and air-conditioning, therefore, hot water is to be circulated during the winter, and chilled water during the summer months. This may be accomplished through utilization of low-pressure steam boilers connected with steam to hot water converters. In the winter months, hot water is pumped to respective zones and individually controlled as previously stated. In the summer months in totally air-conditioned buildings, chilled water may be obtained through the operation of steam absorption refrigeration equipment with the steam obtained by operating the boiler plant during the summer months. The use of the steam absorption refrigeration equipment is recommended to minimize summer electrical peaking of load requirements which has become a critical problem in New York City. Currently, electrical refrigeration equipment actually consumes less source fuel than absorption equipment. It is hoped that two stage absorption chillers will live up to expectations and change this picture.

To optimize efficiency of the refrigeration plant operation, the equipment should be selected so that each refrigeration unit will provide 50 percent of the total required capacity. Schools in the 40,000 to 55,000 sf gross area range should consider reciprocating type of chilling equipment which is available in smaller capacity ranges and will optimize plant efficiency. For very large school projects, it is advisable to consider the use of selective energy and total energy systems to generate electricity on-site. Consideration therefore should be given to the use of exhaust heat available from total or selective energy plants that may be used for absorption refrigeration to provide the necessary chilled water for summer air-conditioning use. Air-conditioning within each classroom can be best achieved through the utilization of fan-coil units that recirculate the air within the classroom. Adequate air supply will be obtained by infiltration and with the operation of the exhaust fan system (see ventilation section). Large air-conditioning distribution systems for places of assembly,

such as auditoriums and cafeterias should utilize cycles which permit the utilization of 100 percent outside air whenever weather conditions permit. Controls should be actuating dampers to reduce the amount of outside air to a minimum required for health standards, whenever the mixed air temperature exceeds 80°F. Above 80° mixed air temperature air dampers maintain minimum position and the chilled water valve to the cooling coil shall open. For extensive air distribution systems, utilize single duct variable volume low pressure air systems. These minimize the fan horse-power required to deliver the cooling air and avoid the necessity for reheat of chilled air to maintain comfort conditions within the space. Wherever distribution systems are contemplated exceeding 150 to 200 feet in length consider multiple fan rooms served from a central chilled water plant. A full analysis should be made of fan room locations to minimize energy consumption.

Partial air-conditioning. Where limited areas only are to be conditioned, consideration should be given to window or through-wall air-conditioning units for single rooms and/or "package-type" air-conditioning equipment distributing chilled air. Consideration should also be given in more extensive systems to the utilization of heat pumps using cooling tower water for chilling or condensing mediums.

Exhaust systems. Where areas are mechanically cooled, the amount of fresh air to be introduced is mainly through infiltration through windows except for air-conditioning of large assembly spaces, where considerable fresh air must be introduced under peak occupancy conditions. The exhaust system should contain a heat exchanger such as a thermal wheel or counter-flow device for air to air heat transfer or an air to water to air loop to permit the regain of energy that would otherwise be wasted. Spaces such as science rooms, kitchens, toilets, locker rooms, should maintain a negative pressure to prevent the transfer of odors into adjacent spaces.

Summary of Findings

Outside air. Rooms without provision for chilled air or water will rely primarily on the introduction of outside air to prevent interior temperatures from rising due to local heat sources such as lights or occupants. This air introduction is to be considered separately from that required for basic metabolic functions which will be discussed under Ventilation. The outside air for cooling can be supplied either mechanically or by air pressure differentials or gravity. Wherever possible, utilize non-mechanical (open windows) to ensure adequate cooling air. Where mechanical means are required, the system is to be isolated from the base ventilating system either physically or by its control system. This is to ensure that regardless of air quantitites introduced for temperature control, sufficient outside air will be supplied for metabolic needs.

d-8/5
Cooling

Evaporative cooling

Provide additional comfort at elevated temperatures by ensuring air movement which results in surface evaporation at the skin. This can be accomplished using oscillating fans, ceiling fans, low speed wall fans, or it can be accomplished by the exhaust system. (Air movement does not require air removal.)

Mechanical Refrigeration

Provide chilled air to portions of the building.

1. Design Standards*

Outdoor - 88° F D.B. 75° F WB
Indoor - 78° F D.B. 60% RH

2. Chillers are to be selected based on energy sources available and demand for heat removal.

3. Primary distribution is to be chilled water.

4. It is recommended that smaller rooms (offices, classrooms, etc.) be heated and cooled with fan coil units of adequate size and number, individually controlled. In this way, the cooling function can be maintained separate from the metabolic outside air requirements.

5. Larger rooms (auditorium, gymnasium, etc.) utilize chilled air from the local air handling unit.

6. With reduced exhaust requirement, no heat recovery is anticipated related to localized chilled water systems. Large, chilled air systems may utilize the same heat recovery systems used for heating.

7. If centralized air distribution is to be used, use variable air volume systems. Avoid terminal reheat systems.

*based on ASHRAE Handbook of Fundamentals, 1972
Ch. 33, Table 1, 5% data; NYC Central Park

d-9

prototypical proposals

9 ● VENTILATING

a) Provide adequate ventilation at all times for the health of the occupants.

b) Avoid introduction of excessive outside air at times when inside air is being heated or cooled.

c) Avoid introduction of outside air to spaces which are unoccupied.

d) Utilize non-mechanical, energy-free means of providing ventilation wherever possible.

e) Design ventilation systems to insure that basic outside air requirements for metabolic well being are provided. Outside air for cosmetic odor and thermal control will not be included in this basic level. Supplemental outside air for these applications may be introduced by two stage controls on the primary system or by secondary systems.

Item "d" may be in partial conflict with items "b" and "c" in that it is more difficult to control exact air flow with non-mechanical means. One basic approach to this situation is to use mechanical means to insure basic adequate ventilation and operable windows to supplement this when higher levels are desired on the assumption that when the occupants of the room desire additional outside air, it is due to the fact that the outside air is closer to desired conditions than inside. When this is the case, thermostatic controls, if working properly, will not be calling for heating or cooling or, if they are, the outside air will be between the inside air conditions and the desired conditions and will therefore reinforce rather than interfere with the mechanical conditioning system.

This approach involves the education and cooperation of the occupants of the spaces. It seems reasonable that as public awareness of the problems of energy use increases,

the willingness to cooperate will increase as will social and administrative pressures. If this turns out not to be the case, mechanical and electronic devices can be installed tc override the various local options in system operation. These might include an interlock system which would prevent windows from being opened while mechanical heating or cooling was taking place. Because of the inherent problems associated with complex systems and the added cost, if cooperation can be achieved, the non-automated approach seems preferable.

Effect of Ventilation on Fuel Use

Ventilation has an effect on energy use in schools in two areas. It uses electrical energy directly to operate fans and motors. This amounts to about 25% of the electricity used. It discharges heated or cooled air to the outside in order to admit the quantity of air called for, for ventilation. Additional energy is required to heat or cool the replacement air. This is responsible for about 65% of the heating or cooling load. In energy terms, in the complete New York City school system, this represents about 17 million gallons of oil, 67 thousand tons of coal and 80 million kwh per year at "pre-crisis" use rates.

Research and observation indicate several important aspects of ventilation as it is currently provided:

Ventilation Standards

1. Standards for minimum quantities of outside air are far in excess of actual requirements averaging about three times more than necessary based on 5 cfm/occupant for sedentary uses and 15 cfm/occupant for high activity areas. Adoption of these basic standards would result in an immediate savings of almost 45% on the heating load. In a typical new building, this would mean a savings of about 225 gallons of oil per year per msf of building. At current prices, this would yield an annual savings of about $75. The electric savings would not be in direct relation to the reduction of fan sizes but a reduction in load of 30% can be anticipated. This would yield a saving of about 290 kwh/yr/msf or $21/yr/msf. Thus, a reduction in outside air requirements of two-thirds the current standards would yield a saving of about $100/yr/msf.

Use Patterns

2. In general, all fans are turned on half an hour or more before classes begin and are often run several hours after the last scheduled class on the basis that some rooms will be used for after school programs. In addition, various spaces are unused for portions of the regular school day. This includes the auditorium (unused about 75% of the time) and gymnasium (about 25% of the time). After school hours, the percentage of use drops drastically. If a control system were available to permit these areas to be taken off the ventilating system when they were not in use, an additional 25% savings could easily be realized. This would yield an additional savings of 27 gallons/yr/msf. If the build-

ing were required to conform to existing ventilation requirements, and the system operated only when required the savings would be over 80 gal/yr/msf.

The ventilation rates proposed are minimum rates designed to provide for all metabolic needs under normal thermal conditions. At times when additional outside air is required to dissipate internal heat gain, it can be introduced by using open windows or by providing a step up in the system that would only be used for excess heat. (See sub-report d-3 'Building Skin'.) The recommendations which follow are in response to the above considerations.

a) The basic criterion for outside air introduction shall be 5 cfm/occupant based on maximum projected occupancy of space.

b) The following major spaces shall be provided with a ventilation rate greater than 5 cfm/occupant:

<u>Gymnasium</u> - 15 cfm/participant
5 cfm/spectator
<u>Cafeteria</u> - 15 cfm/occupant

Note: where cafeteria is to be used as an instructional space, a two-level system is to be provided which can supply 5 or 15 cfm/occupant depending on usage.

<u>Locker Rooms</u> - when possible, interconnect the exhaust system from locker rooms with the gymnasium so that the air that is introduced for gymnasium ventilation is vitiated through the locker area and exhausted through fans interlocked with the gymnasium supply system. Where this is not feasible and a separate supply is used, provide 15 cfm per occupant, and exhaust through sheet metal ductwork connected to the lockers. Ventilation air supply for the lockers should be independent of heating requirements.

<u>Toilet Rooms</u> - 50 cfm/fixture shall be exhausted from toilets. Makeup air shall be from adjacent areas.

c) Labs, shops, kitchen which have equipment which exhausts air directly shall have appropriate makeup outside air introduced near the equipment and coordinated with the duct fan.

Zone Controls

3. Provide zoning with independent control for ventilating systems. The zoning should correspond to that of the heating system. When a portion of the building is in use, only the amount of space in use will be heated and ventilated. This will affect both fuel-oil and

electricity usage.

In addition, it is recommended that several of the classrooms with automated lighting be fitted with automated ventilation controls integrated into the control system which would shut down at the end of each period and start up only if the room was in use as indicated by the activation of any device in the room. In this way, any time a classroom remained empty for a period, the heating load would be reduced by the amount normally required to heat that incoming air. This automation could be achieved in several ways:

a) Provide exhaust registers with mechanized dampers tied to the central signal system. The exhaust function would be handled by a conventional roof fan equipped with a variable speed motor which would modulate fan speed based on the positions of all dampers of grilles which it served.

b) Provide individual exhaust fans similar to residential kitchen fans for each room feeding into a common chase. These fans would be controlled by the central signal system.

Central Console

4. Provide clearly described ventilation zones with all controls directed from a single console conveniently located for custodial staff.

This system would closely resemble current practice of using roof top fans serving small groups of classrooms and individual, indirect heating and cooling systems for major spaces, such as auditoriums and gymnasium. The system would be designed, however, to ensure that no one classroom would rely on more than one fan for its ventilation. In addition, all controls would be taken to a single point so that a custodian supplied with a schedule for the day could operate only those fans which were actually required for each period. This operation could, in fact, be automated and related to the program clock. The desirability of this would have to be evaluated by weighing the possible energy savings resulting from the automation against the complication, expense and control system energy use required by its installation. In a system with controls in a centralized console there is some danger that it might discourage flexible programming and classroom use, since each change would have to be tied in with a change at the central control point.

An alternative to automation would be an information system related to the program clock which would control 2 lights, one red when the fan is not required and one green when the fan is. A third light, green, would indicate that the fan is actually running. At each period, the operator would simply make sure that

whenever a green program signal light was on, a green fan indicator was also on and where a red light was on, that the green was not on. This could, in addition, be coupled with an end of period automatic off function requiring that fans be consciously activated every forty-five minutes, at the start of the next classroom activity.

Seasonal Adjustment

5. Provide seasonally variable ventilation rates by utilizing different fan motors or, in the case of belt-driven fans, several pulley ratios. This approach is particularly applicable to existing installations where it can be used to achieve ventilation rate modulation with a minimum capital input.

Summary of Findings

1. Ventilating will refer to that outside air required for healthy maintenance of metabolic functions.

2. The basic ventilation rates for areas other than those listed below will be 5 cubic feet per minute (cfm) per occupant when space is occupied (Building Department approval is required). This is based on:

   a) Study performed by the National Bureau of Standards in conjunction with this report.

   b) Dr. Ralph Nevins' report included as an appendix to this report.

   c) Latest ASHRAE recommendation.

3. The following spaces shall be provided with a ventilation rate greater than 5 cfm/occupant:

gymnasium	- 15	cfm/participant
	5	cfm/spectator
cafeteria	- 15	cfm/occupant
	5-15	cfm/occupant, if used as instructional space
labs	- 5	cfm/occupant plus special exhaust
shops	- 5	cfm/occupant plus special exhaust
kitchen	- as	determined by exhaust requirements
locker rooms	- 15	cfm/occupant
toilets	- 50	cfm/fixture

4. Ventilating systems will be zoned to be coterminous with heating system zones so that after-school uses can be carried out with the least introduction of outside air by operating the fewest number of zones required. This will affect both fuel-oil and electricity usage. In addition, it is recommended that several of the classrooms with automated lighting be fitted with automated dampers integrated into the conrol system which would close at the end of each period and open only if the room was in use as indicated by the activation of any device in the room. In this way, any

time a classroom remained empty for a period, the heating load would be reduced by the amount normally required to heat that incoming air. The fan serving those damper-controlled areas will be variable speed controlled by SCR devices such as Triacs (section d-11) responsive to the damper position.

d-10

prototypical proposals

10 ● DOMESTIC HOT WATER

a) Provide a source of domestic hot water which will have an output similar to the demand in order to avoid inefficiencies resulting from partial load of boilers.

b) Minimize transmission losses.

c) Utilize low temperature heat to pre-heat incoming street water.

d) Provide hot water at lowest practical temperature.

During the winter the main heating boilers will provide the primary source of heat for domestic hot water. However, at times when there is no space heating demand, even the smallest boiler will be grossly oversized as the source for domestic hot water. This makes necessary either boiler operation at fractional loading, which is highly inefficient, or large storage capacity to permit full loading of the boiler for a period of time and the "coasting" on the accumulated hot water. The problem with large storage facilities is that they lose heat to the surrounding environment while standing. The alternative is to provide a secondary heat source such as a gas or distillate oil fired heater to satisfy demands for hot water when there is no demand for space heat. In this way, the system can operate with small storage and rapid recovery without the need for a large boiler on continuous standby.

There are several ways of reducing heat loss during transmission.

Minimize Length of Runs

The distance from hot water generator to point of use can be reduced by (1) clustering hot water consumers in compact groupings, (2) placing these groupings as close to the hot water source as possible, (3) providing a remote hot water source for large consumers which must be located far from the prime generation point. If distribution runs can be kept very short, an added advantage will be the elimination of

the need for a circulating system. This results in substantial savings in piping costs as well as in reduced heat losses.

Reduce Temperature Differentials

Domestic hot water temperatures of 100° F are sufficient for virtually all school activities except dishwashing which requires 180° F water. This can be accomplished using small boosters where the highest temperatures are actually required. The difference in water temperature from 140° F to 100° F will reduce the differential with ambient temperatures by about half with a corresponding saving in conducted heat loss.

Low Temperature Heat Sources

There are processes which take place in buildings which release heat generally considered to be waste, either because there is no apparent demand for heat, or because the heat is produced at a temperature too low to be used. These include any exhausts from engines, cooling tower water, condensate from steam absorption chillers, blow-down water from boilers and heat captured from exhaust air. In addition, low technology solar collectors can produce relatively low temperature warm water. This can be used to heat or pre-heat water coming from the main into the building. If domestic hot water is distributed at 100° F, a number of these "low temperature" sources will actually provide the total heating required.

Insulation

Insulate hot water lines carefully, particularly in shafts, crawl spaces and furred spaces where lost heat does not contribute even to winter heat requirements.

Faucets

Reduce the pressure of hot water at lavatories. Provide self-closing faucets.

Maintenance

Establish regular program of hot water faucet maintenance to eliminate leaking faucets.

Where total energy or selective energy systems are anticipated, the "waste heat" from major generation points should provide for the entire domestic hot water needs.

d-11

prototypical proposals

11 ● CONTROLS * The effective control of systems which consume fuel in their operation, either directly or indirectly, is essential for energy conservation for a series of closely related but distinct reasons.

a) Activation of systems when tasks actually being performed require their services.

b) Activation of systems when exterior conditions tend to move interior conditions outside pre-selected limits.

c) Activation of systems serving the least area consistent with task requirements.

d) Activation of systems at the lowest levels consistent with task requirements.

The corollary to this also applies. Whenever conditions do not require the use of these fuel-consuming systems, the systems will be deactivated.

In short, mechanical and electrical systems should be controlled to provide their services only where and to the degree they are actually required. This aspect of control is particularly important in an approach to building which stresses reliance on utilizing the natural environment since this will only result in an energy saving when the systems which can be replaced with these natural services are, in fact, deactivated.

The energy efficiency of the building is related to the accuracy, specificity, and flexibility of the system. Those controls that regulate the efficiency of combustion systems -- the burners, the oil flow, the stack tempera-

*Section prepared with the assistance of Karl Sklar, Oyster Bay, New York.

tures, etc. are fairly standard.

The controls that affect energy use at the point of utilization, and those controls that permit greatest advantage to be taken of external conditions merit more discussion here.

Opportunities in Control Systems

There are major savings available in such key systems in schools as lighting, heating and ventilating. If lighting can be used only when it is needed and where it is needed and in the intensity needed, possibly 50 percent of this large energy user might be eliminated. If, after readjusting ventilation levels to more appropriate levels, it was also put into effect only when spaces were occupied, not only would the fan motor energy be reduced, but the energy to heat or cool the excessive replacement air would be unnecessary. If heating and cooling were adjustable on a space by space basis, this would save the energy that goes into spaces that are in larger zones than the activity or occupancy pattern.

The purpose of the study is to point out the improvements in control systems that could be incorporated in the prototype school to keep down energy use.

The opportunities in control systems range all the way from an individual operating a single piece of equipment (a light bulb on a pull chain) to an automatic system that calls for light at a perimeter section, if the room is occupied and if the light level of the lighting system is required.

Solid State Controls

Solid state electronic technology can currently be adapted to building control systems with great promise. Because of its tremendous capabilities, its use requires special caution. Virtually all solid state devices are highly susceptible to automation. There are times when this can be a highly useful approach; however, it can also prove to be negative if applied indiscriminately. The ease of automation increases the possibility of this happening. The problems which occur are four-fold but interrelated. First, an automated system will never anticipate all the variations resulting from human interactions and has no ability to respond to unforeseen situations. Second, in order to minimize these unforeseen happenings, there is a tendency to design buildings and systems to preclude these situations, thus making them less sensitive to actual conditions and more dependent on these automated systems. Third, the removal of responsibility of environmental control from instructional spaces can have a negative educational value in that it provides a false picture of the relationship of people to the spaces that they inhabit, that is, that in a well designed environment, they can consciously modify conditions to meet their needs and, in addition, have the responsibility to do it with sensitivity to energy use, pollution, etc. Fourth, the control of the environment by an "unseen hand" is very likely to promote a sense of help-

lessness in the occupants of a building. This is very likely to turn to resentment and rage towards the building and what it represents.

On the other hand, a building which involves all of those who use it in its operation and control, is much more likely to be viewed sympathetically.

Basic Control Components

Control systems are composed of the following components.

- Sensor - determines the ambient condition of the environmental factor under consideration.
- Evaluator - determines the relationship of the existing ambient conditions to pre-selected parameters.
- Respondor - determines the appropriate mode for the system under control.
- Operator - carries out the actions required to place the system in the desired mode.

In addition to the functions listed above, means of transmitting information between functions must exist. In some cases, two or more functions may be combined into a single component. An example of this is the typical residential thermostat which senses the ambient temperature, determines whether it is within a prescribed zone and closes a contact which is, in effect, a master switch. The effect of closing this switch must then be transmitted to the secondary operators (solenoids, ignitors, pump switches, etc.) at the burner. In many cases, some of the functions are carried out by direct human response. This is the case when a person enters a room, decides that it's too dark for whatever he intends to do, walks to a wall-switch and turns on a light. In this situation, the person acts as the entire control system, sensing, evaluating, deciding on an appropriate response and operating that part of the lighting system which will effect the desired results. There are obvious limitations and penalties related to this type of control system; however, since for the most part, mechanical systems in school buildings are utilized to satisfy human needs and desires, a human sensor and evaluator will frequently produce the most satisfactory responses.

The desire for selectively supplied mechanical and electrical services implies greater subdivision of the systems. For manually operated sub-systems, this requires that the person controlling the sub-system have physical access to the system itself. In some cases, very simple mechanical devices extend a person's normal capacity (such as a pull chain), making possible the operation of a switch located in a fixture at the ceiling. This type of device has the advantage of simplicity, reliability and obvious cause-

effect relationship; however, its range and capacity are limited. As a result, a number of mechanical, electrical and electronic systems have been developed. Recent developments and refinements (currently or shortly to be available) greatly increase the feasibility of utilizing a substantial degree of individual remote control. Some of these applications have been mentioned in the sections on specific systems; however, a somewhat more complete description of the control and signal devices follows.

Electrical Switching Relays

The function of these devices is to effect the actual switching function in an electrical circuit based on receiving a signal from some remote point. The main advantage is that it is not necessary to extend the circuit under control to the point at which the switching decision is made. Instead, the circuit itself can be minimized and a means for transmitting the signal provided from the control point to the operating point.

Bi-State Relays

Bi-state (on-off) relays have one of two basic modes of operation. They can be mono-stable or bi-stable. Mono-stable relays will go to one position (either on or off) unless they are actively receiving a signal to move to the opposite state. Bi-stable relays will stay in whatever position they are in unless they have received a signal to change. Bi-stable relays can function with a single signal in which case each time a signal is received, they change to the opposite position. They can also function with a dual signal in which case each signal selects one or the other state. If the relay is already in the state selected no change will occur.

Mono-Stable Relays

Mono-stable relays have several advantages and at least one distinct disadvantage. They can be utilized in "fail-safe" systems by employing the stable state as an emergency mode so that the interruption of a signal will cause the system to shift to this mode. It also automatically coordinates all relays which are operating from a common signal. The disadvantage is that the signal must be constantly present during one mode of operation.

Bi-Stable Relays

Bi-stable relays with sequential response to a single signal are applicable in situations where one signal operates one relay. Problems develop when more than one relay responds to a single signal due to the fact that any relay which, for any reason is out of phase with the rest, will remain out of phase.

Bi-stable relays which respond to specific selective signals have the advantage of being automatically coordinated and of being stable in whatever position they are in. The disadvantage is that they require the capacity to distinguish between the two signals.

Solid State Relays

The actual switching function can be carried out either by conventional mechanical make-break contacts or by solid

state controls, SCR (silicone controlled rectifier) being the most common and useful general type of device currently in use, The advantages of these solid state control devices include the fact that they have no moving parts, resulting in lower operating wear and they are considerably less expensive than mechanical relays. They currently tend to produce RF (radio frequency) interference, the degree being related to the specific design, and this drawback must be borne in mind should SCR devices be used. The commercial availability of this type of relay is quite recent so the price and availability factors are changing rapidly; however, at the time that control devices are actually selected they will merit very serious consideration.

Multiplex Signaling

Multiplexed control systems which are presently undergoing rapid development and growth are distinct from conventional electrical control systems in that instead of having a separate wire or set of wires running from each switch to the appropriate devices, a single transmission line connects all devices being controlled. The system is basically composed of a small transmitter which, in effect, replaces a series of wall switches, a receiver at each of the devices being controlled, and a line connecting the transmitter with the receivers. The transmitter introduces, into the line, signals which are "addressed", that is, electronically coded. Once a signal is in the line, it travels to all of the receivers, however, only those which are keyed to the specific code (have the same address as the signal) will respond.

The major factor making multiplexing feasible is the evolution of solid state technology, that is, transistors, integrated circuits, etc. This has made possible compact, reliable units which can be economically competitive with other systems. This is the same technology which has produced $3.98 radios and $30.00 pocket calculators.

Multiplexed control systems offer the following advantages over conventional systems:

1. The amount of actual wiring required is drastically reduced.

2. The number of devices which can be separately controlled using a single signal line is limited only by the capacity of the electronic gear.

3. The control patterns are totally flexible within the capacity and range of the system, that is, any point or group of points along the signal line can be assigned or reassigned to any address. This differs from a conventional system where once wiring has been run from a switch to a device, the pattern is relatively firmly established.

4. The system has virtually no moving parts greatly in-

creasing reliability.

The instructions which the transmitter puts into the line can be manual or automated. Manual controls can be given using a series of buttons similar to a push button telephone. Automated controls could come from a program clock, a sensor such as a photo cell, thermostat or smoke detector, or a computer. Before automation is selected, the drawbacks described at the end of this section should be fully weighed.

Multiplexing, then, is simply the ability to put on a single path different signals which can be identified and sorted out at any point along that line. The most versatile approach to addressing signals and having them give proper instruction is digital multiplexing in which binary numerical numbers are used to represent all transmitted information. A brief description of a prototypical system follows.

Prototype Multiplex System

As described earlier, the characteristic of the multiplexed system which makes it desirable is the common signal line or bus which can replace large numbers of individual control circuits. For the example under consideration, the bus can select any of 1024 points (based on a 10 bit binary address the explanation of which follows). In order to use this single path to control large numbers of points, it is necessary to "address" each signal to specified locations, so that those and only those points desired respond to that signal. This is accomplished by an electronic device called a digital multiplexor which transmits, in rapid succession, instructions to each point. Each instruction is preceded by an address. Each remote point is equipped with a receiver which (a) responds to signals bearing its address and ignores all others and (b) interprets the instructions following the address. To this must be added the capability of executing the actual control called for by the instruction, generally some form of mechanical, electric or electronic relay. Thus, the basic elements in the system are the multiplexor, the bus and the receivers. In actuality, the unit at the device being controlled may transmit information as well as receive it. That unit, along with the actual operator is referred to as a bus interface unit in that it handles the entire transition between the bus and the device in question. In addition, a device is connected to the multiplexor which either generates and responds to information processed by the multiplexor or displays this information to permit manual operation. This device with the multiplexor is called a central operating unit.

Manual System

A simple example of a manual system is a number of light fixtures each equipped with a power source which is totally independent of control, a relay switch, and a bus interface unit with a unique address; a signal bus and a central control unit consisting of a multiplexor and a series of on-off signal buttons, one for each bus interface unit with unique address. When it is desired to operate a specific light, the button corresponding to the selected address is

pressed, the multiplexor converts the information (which button has been pushed) into a numerical code which includes the address assigned to the button and the desired operation signified by pressing the button. This signal is introduced into the bus where it goes to all receivers in the system; however, only the one with the specific address responds by becoming susceptible to the instruction which follows and in turn, responds to the instruction itself.

Automated System

A more complex system involving both a two-way flow of information and automation could be illustrated by a lighting control system designed to insure a certain minimum light level at a point where natural light input is a significant but variable factor. This system would be composed of (a) a series of sensors (photo cells) evaluating conditions in specific areas related to specific light sources, bus interface units which identify where information is coming from and what the information is, (b) a series of lights with bus interface units which permit instructions to be selectively received, (c) a central operating unit consisting of the multiplexor which enables the single bus to handle information and signals from and to a large number of identifiable points, and a small computer which interprets the information, selects the appropriate course of action and issues instructions to the multiplexor for transmission to the appropriate device and (d) a bus connecting all bus interface units and the multiplexor which permits a two-way flow of information.

A system with three zones, each with a sensor and light, might be described as having sensors A, B and C which monitor areas affected by lights 1, 2 and 3 respectively. The central operating unit "polls" each of the sensors, one at a time. It sends a signal to each sensor bus interface unit which triggers it to release to the bus the information which it generates. This is in the form of a series of pulses which represent binary bits. This information is then taken from the bus at the central operating unit and given to the computer which determines whether it is in an acceptable range. If the level coming from sensor A is too low, it "instructs" light 1 to increase its output by transmitting addressed signals via multiplexor and bus. If the level is higher than required, the computer will instruct that light 1 reduce its output. These increases and decreases can be achieved in very small increments since even a modest system can "poll" hundreds of points in one second. The central operating unit then goes on to poll sensor B and so forth. This sequential information gathering and signal sending is the basis for digital multiplexing. Because of the speed at which immense numbers of binary digits (0 or 1) can be processed, it is possible to send large quantities of short messages one after another on a single path. By repeating the entire series of messages every second or so and designing the bus interface unit to wait for a succeeding signal or two before initiating a change in the system it controls, it

is possible to send and receive selectively to large numbers of points using this single path.

There are several advantages to using multiplexing as opposed to unique signal carriers. The first is that large numbers of functions can be controlled from a single point with a minimum of wiring. The second, and perhaps the most important is that adjustments, tuning, etc. can be carried out without requiring changes in the physical installation of the control system. A signal directed to bus interface unit B, for example, will get to the desired unit no matter where on the bus it happens to be at any particular time. This type of flexibility can be achieved either by actually moving the interface units from one location to another or by having them adjustable to repond to different addresses.

Binary Numbers

The advantage of using binary rather than decimal systems for electronic information handling is that each digit or bit is described as being in one of two states which is signaled by a positive or negative pulse. With a decimal system it would be necessary to be able to signal ten states for each digit. Thus, while binary numbers require more digits than decimal numbers for equivalent information, it is simpler and more reliable to use them in electronic communication. In describing the addressing of locations, the number 1024 was mentioned. This is the decimal equivalent of binary 1 1 1 1 1 1 1 1 1 1 which is the largest quantity that can be represented by a ten bit binary figure. A typical address, say 343 in decimal would be represented as $0\ 1\ 0\ 1\ 0\ 1\ 0\ 1\ 1\ 1_2$ (binary).

bit weight	512	256	128	64	32	16	8	4	2	1
bit value	0	1	0	1	0	1	0	1	1	1
address		256	+	64	+	16	+	4	+ 2	+ 1 = 343

Summary of Findings

Specific recommendations for system controls are included in each section where systems are described. At the time of this writing, the availability of solid state devices including multiplexed control systems is rapidly increasing with a corresponding reduction in cost. The present schedule requires the installation of control systems in about twenty-two months. By that time, it is anticipated that most of the hardware discussed will be commonly available, compact, reliable and economically competitive with mechanical equivalents. If this is the case, a portion of the control functions should be accomplished using solid state systems.

e

summaries of sub-reports

The following are brief summaries of detailed field observations and statistical data contained in the sub-reports which provided the background information for this report.

FUEL AND ELECTRICITY USE IN NYC SCHOOLS

Fuel use records for all New York City public schools were tabulated and categorized. Selected samples were subjected to monthly and systemic analysis. The results of emergency energy saving measures due to the 1973-74 "crisis" were evaluated.

Annual fuel oil use averaged 523 gal/msf/yr
7.32×10^7 btu/msf/yr

Annual coal use averaged 3.25 tons/msf/yr
9.49×10^7 btu/msf/yr

Electricity use in oil heated schools averaged
3861 kwh/msf/yr

Electricity use in coal heated schools averaged
3110 kwh/msf/yr

Total heating load averaged
6.78×10^6 btu/student/yr

Total electricity load averaged
289 kwh/student/yr

Total source fuel averaged 10.72×10^6 btu/student/yr

Energy use variations resulting from size and age groupings appear to be related primarily to age, with older buildings using more fuel oil and less electricity.

The major areas of energy input into New York City schools

are heating and lighting. Ventilating consumes a substantial quantity of electricity and is responsible for the greatest part of the heating load.

Emergency-Energy Saving Measures instituted by the New York City Board of Education resulted in average savings of 24.4 percent of fuel oil and 20.0 percent of electricity usage in the sixteen sampled schools when compared against the same months for the past three years.

OBSERVED ENVIRONMENTAL CONDITIONS

Observed light levels in twenty classrooms have established that the normal eye has a remarkable ability to adapt to widely ranging light levels. Measurements taken in twenty classrooms have reinforced these findings. The following observations were made: (1) Light intensities were found to be extremely irregular. As reflected in the light contours of the twenty classroom diagrams, light conditions ranged far above and below currently accepted standards. (the New York City Manual of School Planning, 1971 specified 60 foot candles). (2) Light levels were generally unrelated to the tasks being performed. (3) With few exceptions, artificial illumination was in full use, even though daylight, on a clear morning was adequate in a substantial portion of the classrooms. (4) Light control devices were generally used in a haphazard manner, unrelated to actual needs. (5) Chalkboards were invariably poorly lighted. Neither artificial light nor natural light had been directed toward the chalkboards. (6) Teachers and students appeared unaware of the wide fluctuations of light intensities. (7) Light levels fluctuated from minute to minute as clouds reduced the amount of sunlight entering the rooms, reducing maximum light by two thirds. (8) Teachers and pupils were unaware of light differences of 100 times and over in the observed classrooms (6 fc and 800 fc recorded in the same space).

Analysis of Observed Ventilation Performance. Tests were conducted in actual classrooms to observe the effects of various ventilation rates. According to the studies conducted by the National Bureau of Standards, and by Dr. Ralph G. Nevins the following ventilation rates were found to be sufficient and safe:

1. General ventilation for most activities — 5 cfm/occupant
2. Ventilation in areas of intense physical activities — 15 cfm/occupant

SCHOOL LIGHTING

Survey of Lighting Literature and Comparative Listing of Lighting Standards. Light level specifications vary widely as indicated by a survey of lighting standards recommended by government agencies, lighting industry spokesmen, professional organizations, scientists and others interested in the subject of school lighting. Included in the study are excerpts from the literature on light level

determination, lighting and ocular health, and daylighting of schools.

As evident from the chart, "School Lighting Standards: A Comparative Listing of Light Levels", there is little consensus over the "ideal" light level for schoolrooms. Classroom lighting recommendations, for example, range from ± 10 fc (British Government minimum standards of 10 lumens/sf); to 30 fc (New York State Education Department minimum requirements for Public Schools, 1973); to 60 fc (Manual of School Planning for New York City Public Schools); to 70 fc (Illumination Engineering Society recommendations from 'Lighting Handbook' 5th ed., 1972). Actually, the debate over light levels appears to be mostly theoretical, since light, in a partially daylighted space, cannot be held to an exact footcandle level. As observed in the 20 classrooms (sub-report g-1), light levels ranged far above and far below the 60 fc currently required by the Board of Education. It is important to note that teachers and pupils were generally unaware of the wide light level fluctuations, and that these fluctuations did not appear to interfere with the learning process.

Of particular interest in the debate over school lighting are the opinions of independent scientists and educators whose special concern has been the subject of vision and light. Part two of the sub-report summarizes these findings in a survey of the literature on light level determination, lighting and ocular health, and daylighting of schools. Britain's Building Research Station has found that at least four-fifths of school children achieved good standards of vision at 10 lumens/sf and could see well enough to do normal school work, such as reading 3/4" high writing on chalkboard at a distance of 30 feet.

In the U.S., the data of Miles A. Tinker reveal that visual acuity increases rapidly as light intensity is increased from below 1 fc to 5 fc and then gradually increased up to 25 - 40 fc. As the illumination intensity is further increased up to 100 fc or even above 1,000 fc, the improvements in acuity are slight. Taking into consideration also the effect of eye adaptation on visual efficiency, he concluded that 15 -25 fc were adequate light intensities for sustained reading of books and magazines; 25 - 35 fc for reading of small print.

Effects of Light Levels on Reading Scores. In an attempt to determine whether the modernization program carried out by the Board of Education of New York had any effect on the performance of pupils, standard reading/comprehension scores recorded in schools before and after modernization were compared with scores recorded in unaltered schools. The modernization program included the increase of artificial lighting from 5 - 7 fc to a design level of 60 fc.

e/4
Summaries of Sub-reports

The test results from 18 classes have been plotted (sub-report h-3) and from these charts the following generalizations can be made:

During the six-year period, the average of reading scores of all schools declined.

The modernized schools showed improved relative performance in the year immediately after their renovation.

Two years after the renovation, the modernized schools showed a relative decline and returned to approximately the same relative position from which they started.

EDUCATIONAL TASKS AND ENVIRONMENTAL CONDITIONS

Observation of Typical School Tasks. This study consisted of an investigation into the typical activities of a school. A team of observers-architects and members of the New York Board of Education recorded possible teaching/learning activities, and listed concurrently: 1. The type of student grouping (students working singly, in small groups, in standard class sizes or larger); 2. The presence of teachers, para-professionals or other personnel; 3. The types of teaching aides or special equipment; 4. The space designation (classroom, art room, shops and specialized teaching spaces, auditorium, cafeteria, corridor, library, gymnasium, staff offices); and 5. The actual student stations (desks, carrel, station at equipment, etc.).

Assignment of desirable environmental values for Lighting, Temperature, and Ventilation. Environmental values were assigned to each of the separate tasks, based on direct observation, on the studies outlined in this report and in the various sub-reports, and on surveys of the pertinent literature.

By separating the educational activities into their component parts, it was possible to be more specific in assigning values to the "desirable environmental conditions". In the area of lighting, for example, this itemized system has made it possible to assign light intensities to each specific task. In contrast to the currently prescribed uniformly high light levels (60 - 70 fc based on the light requirements of the most exacting task within each space), the alternative method suggests a lower ambient light level, supplemented by light sources focused directly onto specific educational tasks. This method offers several advantages: First, it avoids fixed illumination levels which tend to be monotonous and fatiguing. Second, the brightest light levels will be concentrated on those teaching/learning areas on which the attention of the student should be focused. Third, it is expected that by these means a large part of the electric consumption of a school can be reduced.

f-1

fuel and electricity use in nyc schools

1 ● ANNUAL ENERGY USAGE FOR ALL SCHOOLS

The energy use in New York City schools was evaluated in several different ways.

Annual usage for all schools. Based on the record keeping methods of the New York City Board of Education, this was broken down into four major subgroups:

a) Fuel Oil Usage
b) Coal Usage
c) Electricity Usage in Oil Heated Schools
d) Electricity Usage in Coal Heated Schools

More detailed evaluation was based on samples taken from the oil heated schools because of the greater similarity of these schools to schools currently being constructed, which in turn are the norm on which variations leading to the new prototype are based. This information is reported in this section.

Annual Fuel Oil and Electricity Usage by Building Size. This information is reported in section f-2.

Annual Fuel Oil and Electricity Usage by Building Age. This information is reported in section f-2.

Monthly Fuel Oil and Electricity Usage. This information is reported in section f-3.

Profile of Energy Consumption in Typical Building (Theoretical) This information is reported in section f-4.

Profile of Energy Consumption in Selected School Buildings. School #6 of the examples in the Monthly Fuel Oil and Electricity Usage section was subjected to a detailed analysis by the National Bureau of Standards. Recorded data, on-site visits and careful review of the construction drawings provided the basis for a computer simulation, using the NBSLD program. The resulting projection of energy use were

compared against the actual recorded fuel use. The results are included in the NBS Phase I Interim Report (a companion document).

Preliminary Analysis of Energy-Saving Measures Initiated by the New York City Board of Education 1973-74. This information is reported in section f-5.

ANNUAL FUEL OIL USAGE PATTERNS

The fuel oil use records of 499 schools were evaluated for patterns and variations related to the mean consumption. The sample represented 56,687 msf of building area. The average size of sample was 113 msf. Data were taken for the year 1972-73. A total of 29,641,068 gallons of oil was consumed. The mean for the schools was 519 gal/msf, standard deviation was 154 gal/msf and the weighted average was 523 gal/msf, 210 buildings were above the average, 289 below it.

The portion of fuel use of the 210 high consumption schools which is above the weighted average accounts for 2,738,800 gallons of oil annually or about 10 percent of the total; 769,100 gallons of this amount (almost 30 percent) were used by 10 buildings ranging in size from 208 to 594 msf. All but one of these schools were built before 1940 (average age, 42 years, average size 296 msf). Eight schools in a similar size range (280-375 msf) but built after 1950 (average age 10 years) showed an average fuel oil usage of 432 gal/msf/yr, over 17 percent below the overall average.

Small schools, those below 50 msf also showed a relatively high overall energy use pattern. Twenty-two of the 39 buildings in this category were above the average in fuel oil usage. In this size range, the six buildings built after 1950 exhibit a very high fuel use average of 727 gal/msf/yr. From 50 to 59 msf, the average for schools built after 1950 drops to 527 gal/msf/yr which is slightly above the overall average. From 60 through 69 msf, the average is 563 gal/msf/yr and from 70 to 79 msf the average is 550 gal/msf/yr.

The middle range of school sizes, 80 to 180 msf, exhibits fuel use patterns sharply lower than the extreme. This group includes 285 buildings comprising a total of 33,166 msf (59 percent of the total) yet it used 15,915,840 gallons of fuel oil in 1972-73 (54 percent of the total). These buildings use an average of 480 gal/msf/yr, showing a saving of 43 gal/msf/yr when compared with the overall average. It should be pointed out that this group was also built recently, having an average age of 19 years. Eighty-eight of the buildings in this group are above the weighted average use of 523 gal/msf/yr and 197 below it. That is 31 percent of the buildings in this group have above average use as opposed to the overall group in which 42 percent are above average. Of the 88 schools in this middle range which are above the average, 38 of the 88 were built before 1950. If the range were further narrowed to include only schools built after 1950, the data would be as

follows: The sample is 234 schools having a total area of 27,602 msf and a fuel consumption of 12,621,031 gallons for an average of 457 gal/msf/yr. Fifty of this group or about 21 percent fall above the weighted average for the total. The group shows a standard deviation of 110 gal/msf/yr from a mean of 465 gal/msf/yr. These buildings between 80 and 180 msf in area and built after 1950 comprise 49 percent of the original sample (all oil-heated New York City Board of Education Schools) and used 42½ percent of the fuel oil. If the 51 percent of the sample which remains (buildings under 80 msf, over 180 msf or built before 1950) performed as efficiently, the total fuel oil consumption would have been 25,905,959 gallons of oil for the 1972-73 season, or a saving of 3,735,000 gallons. It can be said that this selected group of schools uses 12½ percent less fuel per unit area than the overall group. If the low-energy-use half of the sample discussed above is compared with the high-energy-use half (457 gal/msf/yr against 585 gal/msf/yr) the middle range schools use almost 22 percent less fuel oil per unit area.

ANNUAL ELECTRICITY USAGE PATTERNS

The electrical energy use records of 461 schools were evaluated for patterns and variations related to mean consumption. This group was taken from the 499 oil-fired schools. Schools with incomplete electric records were deleted from the sample. The sample represented 54,214 msf of building area (average size per school 118 msf). Data were taken for the year 1971-72. A total of 209,324,174 kwh was used resulting in an overall average of 3,861 kwh/msf/yr for the entire sample. The sample had a mean for all schools of 3,637 kwh/msf/yr and a standard deviation of 1,403 kwh/msf/yr. The schools from 80 to 180 msf were analyzed. This group included 269 schools with a total area of 30,671 msf. The electrical use for these buildings was 108,648,499 kwh or an average of 3,542 kwh/msf/yr. When the schools built before 1950 are dropped from the sample, it becomes a total of 222 schools having a total area of 95,471 msf, a total annual electricity usage of 91,449,099 kwh or an average of 3,590 kwh/msf/yr and a standard deviation of 1,445 kwh/msf/yr from a mean of 3,883 kwh/msf/yr. It is interesting to note that in this case, unlike that for fuel oil, the effect of the older buildings in the sample is relatively small.

The smaller schools, 0 to 79 msf included 139 buildings with a total area of 8,584 msf and a total annual electric use of 26,344,085 kwh for an average of 3,069 kwh/msf/yr, and a standard deviation of 1,206 kwh/msf/yr from a mean of 3,126 kwh/msf/yr.

Schools larger than 180 msf included 53 buildings having a total area of 14,960 msf and a total annual electric use of 65,817,300 kwh or an average of 4,400 kwh/msf/yr.

CONCLUSIONS

These data raise several significant questions regarding the energy consumed in the sample. In the case of the fuel oil use, it is useful to isolate the factors which have led to

the pronounced drop in use in more recent buildings in order to codify or reinforce these factors in new New York City school buildings and to make the accumulated working knowledge obtained by the Board of Education available to other building agencies which do not have the same experience. It is also important to identify the factors which have resulted in the wide range of usage patterns within each group. These local variations are also important with respect to electrical usage, since these records indicate wide fluctuations from building to building without establishing the same clear pattern of change shown by the fuel oil usage.

Performance of Equipment and Fuel Use

The first factor which can be cited in the reduction of fuel oil use in recent buildings is the improved performance of new equipment. Boiler efficiencies have steadily increased, control and monitoring equipment has progressed and delivery devices have become more precise in their performance. It should be pointed out that this holds true for buildings which use the standard method of low pressure steam to convectors or radiators in most areas, and coil-heated air to large spaces such as the gymnasium and auditorium. The observed experience thus far with more complex systems is that they use considerably more fuel oil in their operation. It is worth noting that the major failings of these systems (unit ventilators with dampers controlling outside air) seem to result directly from their multiplicity of controlled operations, and from the failure of these operations to function properly. The consequences are over-delivery of heat and lack of proper maintenance of these systems due to the inability of a conventionally sized school maintenance staff to deal with the complex equipment.

Control of Energy Loss by Conduction and Infiltration

A second factor of major importance is the improved thermal performance of component parts of buildings. This relates to both factory and field assembled elements and includes control of energy loss by conduction and infiltration. Recent standards adopted by the Board of Education have reinforced the trend in this direction, however, it will be several years before the results of these standards begin to appear in the records. Of particular concern in most school construction is the roof since schools, being relatively low buildings, have a high percentage of roof area. The following up-dated design criteria were specified by the Division of School Buildings on February 27, 1974:

A. Walls shall have U-value of 0.10
B. Roofs shall have U-value of 0.12
C. Double-hung windows: the air infiltration permitted shall not exceed .250 cfm/running foot of sash perimeter at a wind velocity of 25 mph.
D. Projected-type windows: the air infiltration permitted shall not exceed .125 cfm/running foot of sash perimeter at a wind velocity of 25 mph.

Configuration of Building and Fuel Usage

A third important factor in fuel use is the configuration of the building package itself. Newer building techniques and mechanical systems have permitted lower floor-to-floor heights thereby reducing the amount of exterior surface which acts as a radiator to the outside. If a 100 ft by 200 ft by four-story building has a floor-to-floor height reduced from 15'0" to 12'0", this results in a 20 percent reduction in exterior wall surface or a 13 percent reduction in total exterior surface, including the roof. It is important here to note the difference between useful and wasted exterior surface. The typical recent school building with 5'0" to 6'0" high windows running continuously along the outside walls of the classrooms is potentially an energy saving arrangement (see studies on 'Building Skin' and 'Solar Energy') due to the ability to capture natural light, ventilation, and in some cases, heat, which compensates for the added heat loss through glass. On the other hand, it is generally desirable to hold to a minimum those exterior walls that do not take advantage of the natural environmental services available. These walls serve only as a means of uncontrolled transmission of energy to the outside. It is worth noting two school buildings observed which could be described as "windowless" i.e., windows were provided only to give visual contact with the outdoors but not used to modify in any way the interior environment. These buildings, although in the low fuel use grouping by age and size, exhibited extremely high fuel oil consumption, one having the seventh highest use per sf of all 499 schools observed.

SUMMARY OF ENERGY USE

Fuel Oil		
Number of Schools	499	
Total Gross Area	56,678	msf
Annual Oil Usage (72-73)	29,641,068	gallons
Btu Equivalent	523	gal/msf/yr
	7.32×10^7	btu/msf/yr
Coal		
Number of Schools	454	
Total Gross Area	35,263	msf
Annual Coal Usage (71-72)	114,632	tons
Average Annual Coal Usage	3.25	tons/msf/yr
Btu Equivalent	9.49×10^7	btu/msf/yr
Electricity in Oil-Heated Schools		
Number of Schools	461	
Total Gross Area	54,214	msf
Annual Electricity Usage (71-72)	209,324,174	kwh
Average Annual Usage	3,861	kwh/msf/yr
Btu Equivalent at School	1.32×10^7	btu/msf/yr
Btu Equivalent at Generator	5.27×10^7	btu/msf/yr
Electricity in Coal-Heated Schools		
Number of Schools	461	
Total Gross Area	35,590	msf
Annual Electricity Usage (71-72)	110,703,317	kwh
Average Annual Electricity Usage	3,110	kwh/msf/yr
Btu Equivalent at School	1.06×10^7	btu/msf/yr
Btu Equivalent at Generator	4.24×10^7	btu/msf/yr
Total Heating Load		
Btu Equivalent of Oil Used =	4.15×10^{12}	btu/yr
Btu Equivalent of Coal Used =	3.35×10^{12}	btu/yr
Total Btu Equivalent	7.50×10^{12}	btu/yr
The Current School Population is	1,106,800	students
resulting in:	6.78×10^6	btu/yr/student
Total Electric Load (at Generator)		
Total Electricity Used in Oil-Heated Schools:	209,324,174	kwh/yr
Total Electricity used in Coal-Heated Schools:	110,703,317	kwh/yr
	320,027,491	kwh/yr
Which results in	289	kwh/yr/student
Btu Equivalent at School	0.99×10^6	btu/yr/student
Btu Equivalent at Generator	3.94×10^6	btu/yr/student
Total Source Fuel Use by New York City Board of Education		
Btu Equivalent Total	11.87×10^{12}	btu/yr
which results in	10.72×10^6	btu/yr/student

f-2

fuel and electricity use in nyc schools

2 ● ANNUAL ENERGY USAGE BY SCHOOL SIZE AND AGE

Annual Fuel Oil and Electricity Usage by Building Size. A series of building size ranges were selected and the average annual energy usages for all buildings within each range were determined. The results of this study are shown in figures f-2/1 to f-2/4. Purpose of the study was to determine whether there was any correlation between building size and energy use. It was anticipated that the major factor affecting these groupings would be the differences in programs of small (generally, elementary schools) and large (generally, high schools) buildings. Plotting of the data, however, produced no clear relationship between size and energy use. What was observed is that because building programs stressed certain typés of schools at certain times, the different size categories have distinctly different average ages. When these average ages were plotted against fuel oil use, it was possible to generate similar trends. This was primarily important in suggesting the next evaluation since the results of these plots is of limited use due to the fact that the actual spread of ages is not shown. The average years of construction of the schools and the number of samples in each range are also shown in the illustrations.

Annual Fuel Oil and Electricity Usage by Building Age. The same group of buildings evaluated in the previous study were rearranged into groups based on the year of completion. Each group covered a ten-year period. The results are shown in figures f-2/5 to f-2/8. The purpose of this study was to determine whether there was any correlation between the time when a building was constructed and energy use. The major factors anticipated as affecting these groupings are changes in building configuration, construction standards, mechanical technology and the general wear and tear on the older buildings. A clear pattern was found in fuel oil use showing a steadily decreasing consumption for newer schools. The average sizes of the schools and the number of samples in each range are also shown in the illustrations.

Area (NYC B of E Definition) msf	Average Year of Completion	Number of Schools in Sample	gal/msf/ Deg. Day 1970-1973
20 - 30	1922	7	.143
45 - 55	1946	8	.133
65 - 75	1948	51	.126
95 - 105	1952	20	.107
145 - 155	1960	30	.093
185 - 215	1931	6	.125
235 - 265	1945	19	.123
285 - 325	1948	7	.111
325 - 375	1943	4	.141
375 - 325	1930	2	.115
ALL SCHOOLS		155	.118

Note: Data supplied by Board of Education, City of New York Division of School Building, Office of Fuel Management.

FIGURE f-2/1:
LOW ENERGY
UTILIZATION
SCHOOL
FUEL OIL USE
BY BUILDING
SIZE

f-2/3
Fuel and
Electricity Use

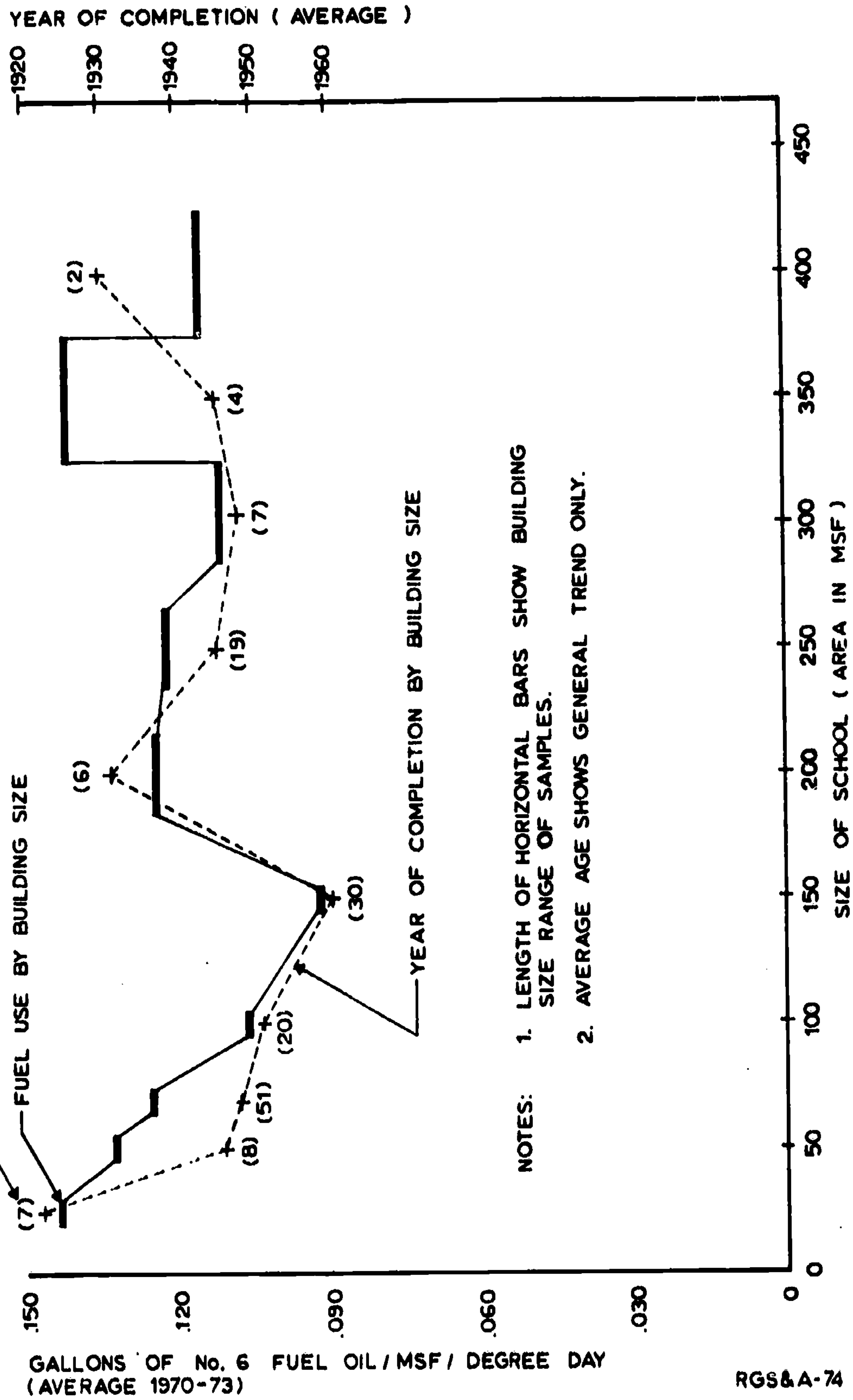


FIGURE f-2/2:
LOW ENERGY
UTILIZATION
SCHOOL
FUEL OIL USE
BY BUILDING
SIZE

Area (NYC B of E Definition) msf	Average Year of Completion	Number of Schools in Sample	kwh/msf/yr 1970-1971
20 - 30	1917	6	2996
45 - 55	1946	8	3129
65 - 75	1948	48	3059
95 - 105	1951	19	4107
145 - 155	1960	29	3618
185 - 215	1931	6	3293
235 - 265	1945	20	4799
285 - 325	1948	7	4076
325 - 375	1945	3	3574
375 - 425	1930	3	3194
ALL SCHOOLS		149	3668

Note: Data supplied by Board of Education, City of New York Division of School Building, Office of Fuel Management.

FIGURE f-2/3:
LOW ENERGY
UTILIZATION
SCHOOL
ELECTRICITY
USE BY
BUILDING
SIZE

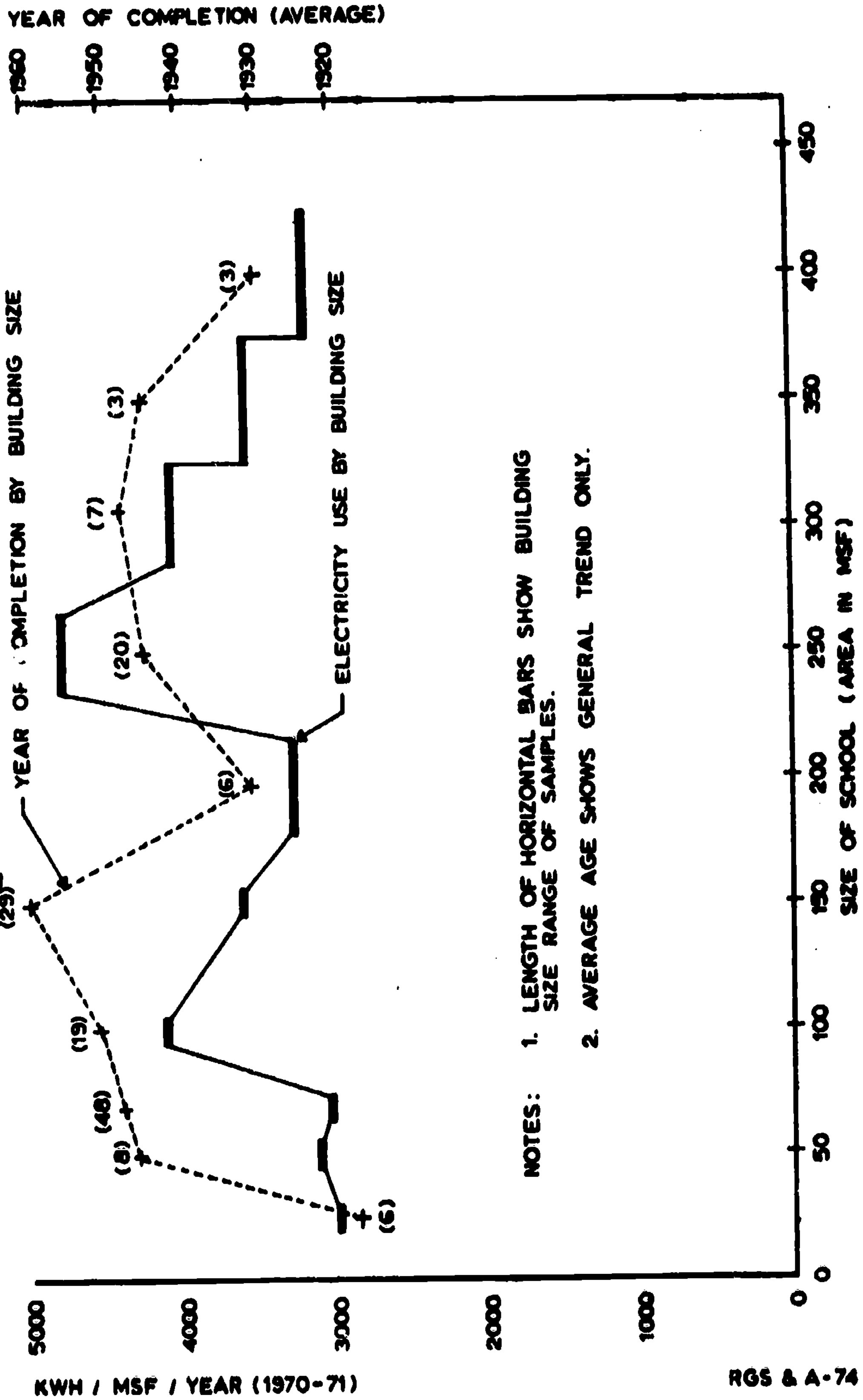


FIGURE f-2/4:
LOW ENERGY
UTILIZATION
SCHOOL
ELECTRICITY
USE BY
BUILDING
SIZE

Year of Completion	Average Area (msf)	Number of Schools in Sample	gal/msf/ Deg. Day 1970-1973
1900-1909	32	4	.146
1910-1919	120	2	.155
1920-1929	246	9	.146
1930-1939	180	16	.139
1940-1949	92	12	.134
1950-1959	118	39	.123
1960-1969	149	48	.096
ALL SCHOOLS		130	.134

Note: Data supplied by Board of Education, City of New York Division of School Building, Office of Fuel Management

FIGURE f-2/5
LOW ENERGY
UTILIZATION
SCHOOL
FUEL OIL USE
BY AGE
OF SCHOOL

f-2/7
Fuel and
Electricity Use

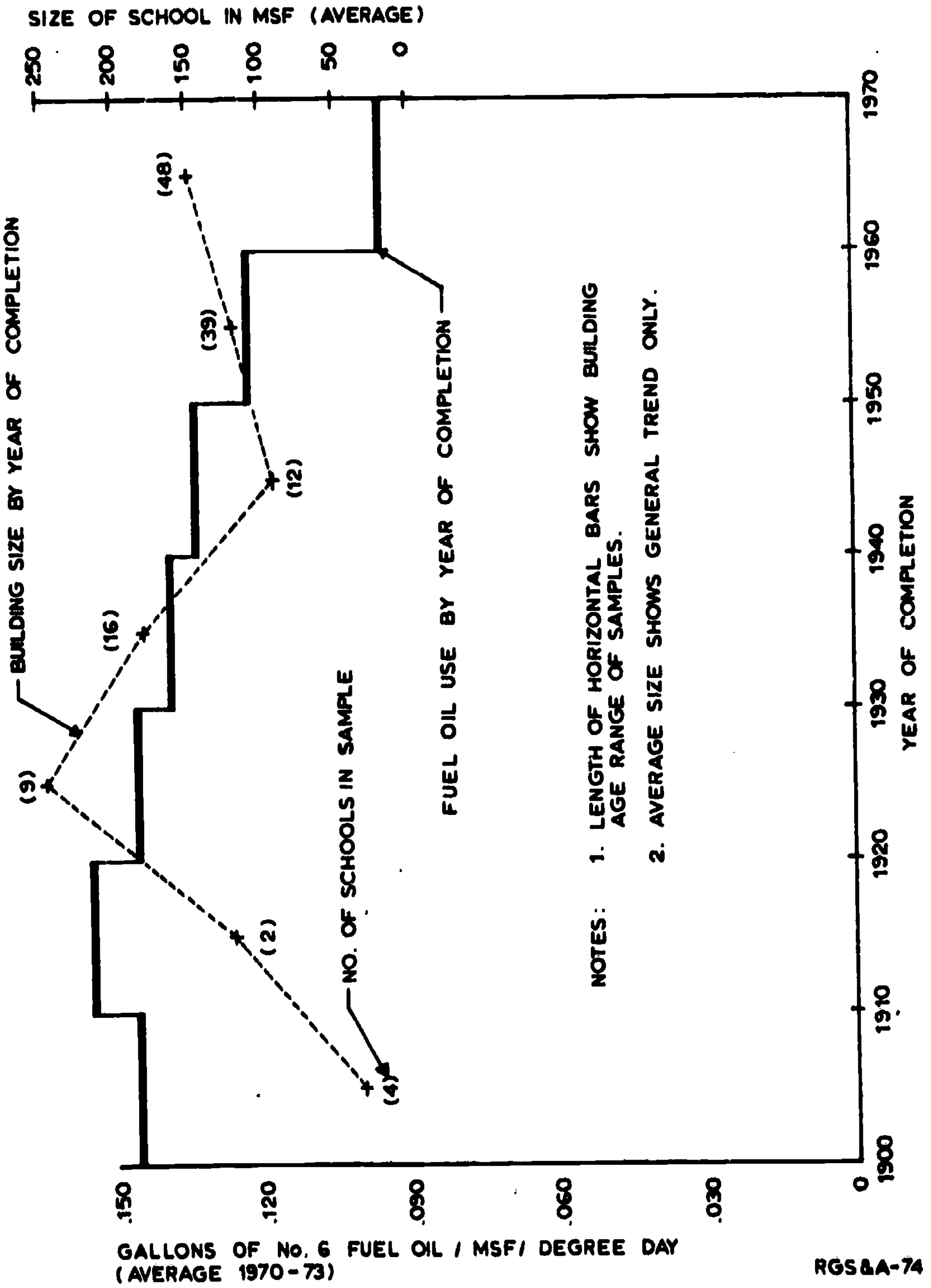


FIGURE f-2/6:
LOW ENERGY
UTILIZATION
SCHOOL
FUEL OIL USE
BY AGE
OF SCHOOL

Year of Completion	Average Area (msf)	Number of Schools in Sample	kwh/msf/yr 1970-1971
1900-1909	48	6	3420
1910-1919	100	3	3093
1920-1929	245	9	4215
1930-1939	167	15	3630
1940-1949	109	12	3725
1950-1959	114	36	3507
1960-1969	135	46	4056
ALL SCHOOLS		127	3664

Note: Data supplied by Board of Education, City of New York Division of School Building, Office of Fuel Management.

FIGURE f-2/7
LOW ENERGY
UTILIZATION
SCHOOL
ELECTRICITY
USE BY
AGE OF
SCHOOL

f-2/9
Fuel and
Electricity Use

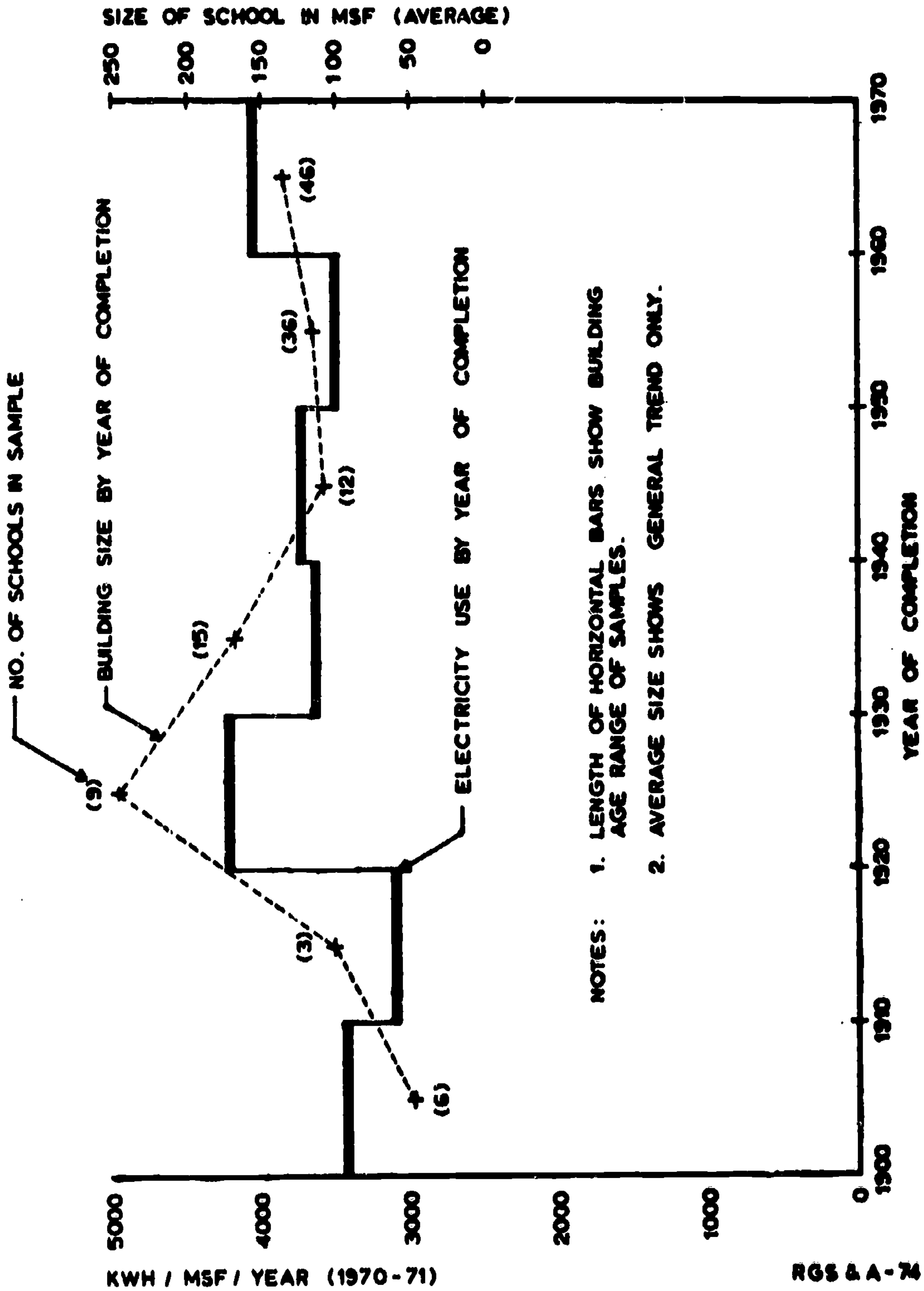


FIGURE f-2/8:
LOW ENERGY
UTILIZATION
SCHOOL
ELECTRICITY
USE BY
AGE OF
SCHOOL

f-3

fuel and electricity use in nyc schools

3 ● MONTHLY USAGE OF SELECTED SAMPLES

Monthly Fuel Oil and Electricity Usage. The monthly records of fuel oil and electricity use for sixteen recent intermediate and high schools were gathered and are presented on the following pages. Of particular interest within the information covering each school is the comparison of the three years 70-71 to 72-73 with 73-74. In November and December 1973, an emergency effort towards energy conservation was made in response to the fuel crisis.

f-3/3
Fuel and
Electricity Use

SCHOOL NO. 1: High School, Brooklyn
Year of Completion: 1964

BUILDING DESCRIPTION

Size: 248 msf
Floor to Floor Height: 10'-8 5/8"
Type of Construction: reinf. conc.
Skin: 4" glazed brick, 2" air, 6" block
No. of Levels: 3
Ratio: Window Area to Skin Area of Typical
Classroom Elevation: 42%
Ratio: Window Area to Typical Classroom Area: 19%
Ceiling Height of Typical Classroom: 8'-5"
Roof Insulation: 2"

BOILER PLANT

No. of Boilers: 4
Burner Capacity: 6 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

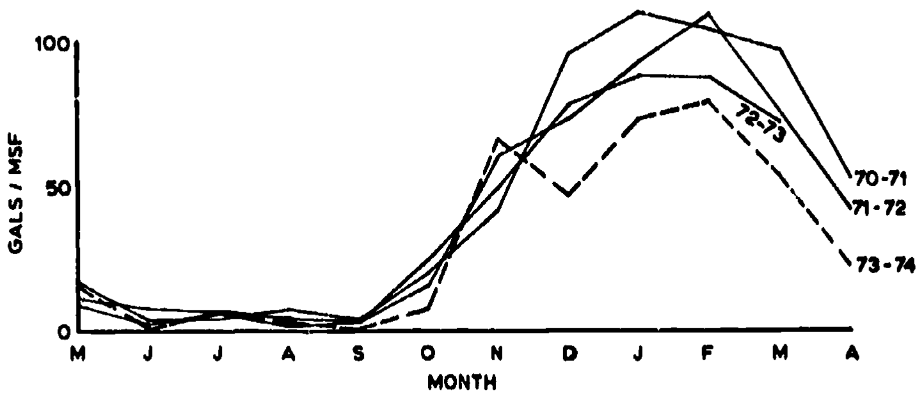
Type: open window
Type of Exhaust System: central fan
Cfm/Typical Classroom: 560
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	20,400	21,100
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	manual	manual

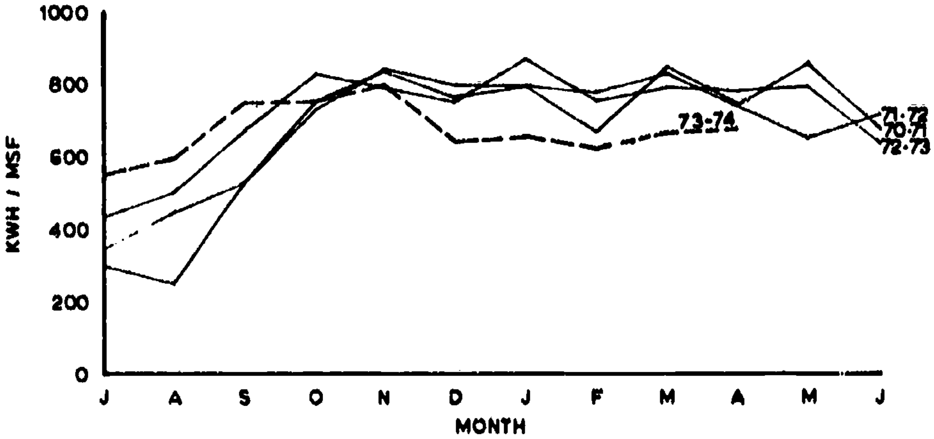
ELECTRICAL

Watts/sf Typical Classroom: 2.4 Fixtures: fluorescent
Watts/sf Corridor: 0.92 Fixtures: fluorescent
Total Fan H.P.: 93
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen: yes

FIGURE f-3/1:
SCHOOL NO. 1



FUEL OIL USAGE



ELECTRICITY USAGE

SCHOOL No. 1: HIGH SCHOOL, BROOKLYN

SIZE: 248 MSF
YEAR OF COMPLETION: 1964

RGS & A-74

FIGURE f-3/2:
SCHOOL NO. 1

SCHOOL NO.1: HIGH SCHOOL
BROOKLYN

SIZE: 248 MSF
YEAR OF COMPLETION: 1964

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY	3860	2200	2700	3800
JUNE	980	700	1700	173
JULY	1020	1300	1413	1500
AUG	1814	300	1044	400
SEPT	1100	1067	873	214
OCT	5170	3970	N A	1800
NOV	10629	15151	18386	16237
DEC	24002	18305	19757	11771
JAN	27309	22965	21895	18316
FEB	25871	26988	21678	19603
MAR	24146	18648	18165	13353
APR	13046	10313	N A	5514

FUEL OIL USAGE (GAL/MSF)

70-71	71-72	72-73	73-74
15.56	8.87	10.89	15.32
3.95	2.82	6.85	0.70
4.11	5.24	5.70	6.05
7.31	1.21	4.21	1.61
4.44	4.30	3.52	0.86
20.85	16.01		7.26
42.86	61.09	74.14	65.47
96.78	73.81	79.67	47.46
110.12	92.60	88.29	73.85
104.32	108.82	87.45	79.04
97.38	75.19	73.25	53.84
52.60	41.58		22.23

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	72,000	92,400	108,000	135,600
AUG	56,400	109,200	120,000	145,200
SEPT	133,200	129,600	164,400	183,600
OCT	186,000	180,000	205,200	184,800
NOV	201,600	201,600	193,200	195,600
DEC	196,800	188,400	184,800	158,400
JAN	196,000	196,800	212,400	159,600
FEB	164,400	192,000	186,000	153,600
MAR	208,800	201,600	195,600	164,400
APR	172,800	180,000	193,200	166,800
MAY	210,000	210,000	196,800	
JUNE	164,400	177,600	168,000	

ELECTRICITY USAGE (KWH/MSF)

70-71	71-72	72-73	73-74
290	373	435	547
227	440	484	585
537	523	663	740
750	726	827	745
813	813	779	789
794	760	745	639
794	794	856	644
663	774	750	619
842	813	789	663
697	726	779	673
847	647	794	
663	716	677	

ELECTRICITY DEMAND

70-71	71-72	72-73	73-74
180	204	324	240
192	N A	228	252
468	N A	480	480
516	492	504	480
516	492	492	492
552	504	492	492
528	492	516	420
516	480	504	420
516	492	492	348
504	492	492	444
504	492	480	
492	468	420	

FIGURE f-3/3:
SCHOOL NO. 1

f-3/7
Fuel and
Electricity Use

SCHOOL NO. 2: HIGH SCHOOL, QUEENS
Year of Completion: 1960

BUILDING DESCRIPTION

Size: 246 msf
Foor to Floor Height: ± 11'-0"
Type of Construction: NA
Skin: 4" brick, 2" air, 6" block
No. of Levels:
Ratio: Window Area to Skin Area of Typical Classroom Elevation: 38%
Ratio: Window Area to Typical Classroom Area: 14%
Ceiling Height of Typical Classroom: NA
Roof Insulation: NA

BOILER PLANT

No. of Boilers: 4
Burner Capacity: 62 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

Type: open window
Type of Exhaust System: central fan
Cfm/Typical Classroom: 560
Air-Conditioning: none

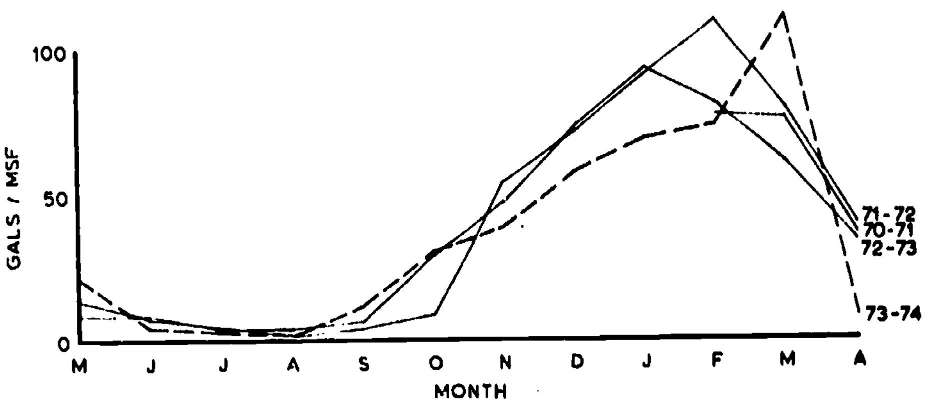
	Gymnasium	Auditorium
CFM:	21,000	19,200
% Outside Air:	100	
Recirculation:	yes	
Controls:	manual	

ELECTRICAL

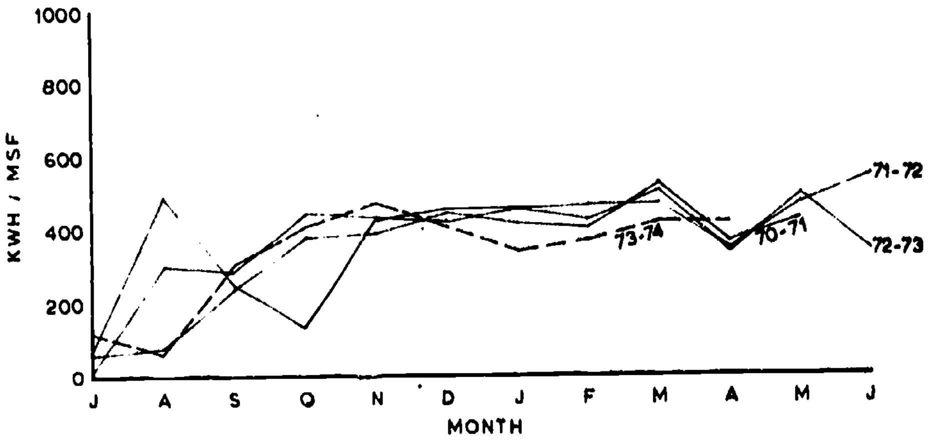
Watts/sf Typical Classroom: 2.75 Fixtures: fluorescent
Watts/sf Corridor: 1.3 Fixtures: fluorescent
Total Fan H.P.: 100
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen: yes

FIGURE f-3/4:
SCHOOL NO. 2

f-3/8
Fuel and
Electricity Use



FUEL OIL USAGE



ELECTRICITY USAGE

SCHOOL [illegible] 2 : HIGH SCHOOL, QUEENS

SIZE. 246 MSF
YEAR OF COMPLETION: 1960

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FIGURE f-3/5:
SCHOOL NO. 2

SCHOOL NO. 2: HIGH SCHOOL
QUEENS

SIZE: 246 MSF
YEAR OF COMPLETION: 1960

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY		3,216	2,200	5,078
JUNE		1,300	1,400	1,000
JULY			570	600
AUG		400	952	400
SEPT		800	1,300	2,770
OCT		2,013	7,179	7,179
NOV		13,370	11,565	9,540
DEC		17,356	17,930	14,140
JAN		22,226	23,025	16,970
FEB	18,844	26,467	19,740	18,300
MAR	18,585	19,2[illegible]0	14,743	27,753
APR	9,013	9,437	8,200	1,703

FUEL OIL USAGE (GAL/MSF)

70-71	71-72	72-73	73-74
	13.07	8.94	20.64
	5.28	5.69	4.06
		2.39	2.44
	1.63	3.87	1.63
	3.25	5.28	11.26
	8.18	29.18	29.18
	54.35	47.01	38.78
	70.55	72.89	57.48
	90.35	93.60	68.98
76.60	107.56	80.24	74.39
75.55	[illegible].29	59.93	112.82
36.64	38.36	33.33	7.17

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	14,640		3,420	31,080
AUG	19,560	144,540	76,320	17,760
SEPT	59,520	60,180	70,380	76,200
OCT	92,460	34,380	108,960	101,760
NOV	96,000	107,280	107,760	117,900
DEC	104,280		103,800	101,460
JAN	101,940	224,760	112,080	85,180
FEB	99,540	116,040	104,280	91,320
MAR	128,400	116,580	126,240	104,340
APR	89,040	87,480	87,300	103,900
MAY	107,160	116,400	120,420	
JUNE		134,820	83,040	

ELECTRICITY USAGE (KWH/MSF)

70-71	71-72	72-73	73-74
60.		14	126
80	588	310	72
242	245	286	310
376	140	443	414
390	436	438	479
424		422	412
414	914	455	346
405	472	424	371
522	474	513	424
362	356	355	422
436	473	490	
	548	338	

ELECTRICITY DEMAND

70-71	71-72	72-73	73-74
144.0			204
124.0	384.0	452	112
472.0	496.0	488	468
496.0	488.0	488	496
492.0	534.0	508	520
744.0		488	528
520.0	044.0	484	484
512.0	504.0	504	488
504.0	500.0	108	504
500.0	488.0	904	492
484.0	528.0	516	
	528.0	480	

FIGURE f-3/6:
SCHOOL NO. 2

SCHOOL NO. 3: INTERMEDIATE SCHOOL, MANHATTAN
Year of Completion: 1966

BUILDING DESCRIPTION

Size: 170 msf
Floor to Floor Height: 10'-6"
Type of Construction: reinf. conc.
Skin: 4" brick, 2" air, 4" block
No. of Levels: 3
Ratio: Window Area to Skin Area of Typical
Classroom Elevation: 0%
Ratio: Window Area to Typical Clssroom Area: 0% (windowless school)
Ceiling Height of Typical Classrm: 8' -0"
Roof Insulation: lightweight conc. fill of varying depth

BOILER PLANT

No. of Boilers: 3
Burner Capacity: 99 gal/hr
Type of Boiler: fire box
Heating System: hot water
Type of D.H.W. Generation: heat exhanger

VENTILATION SYSTEM

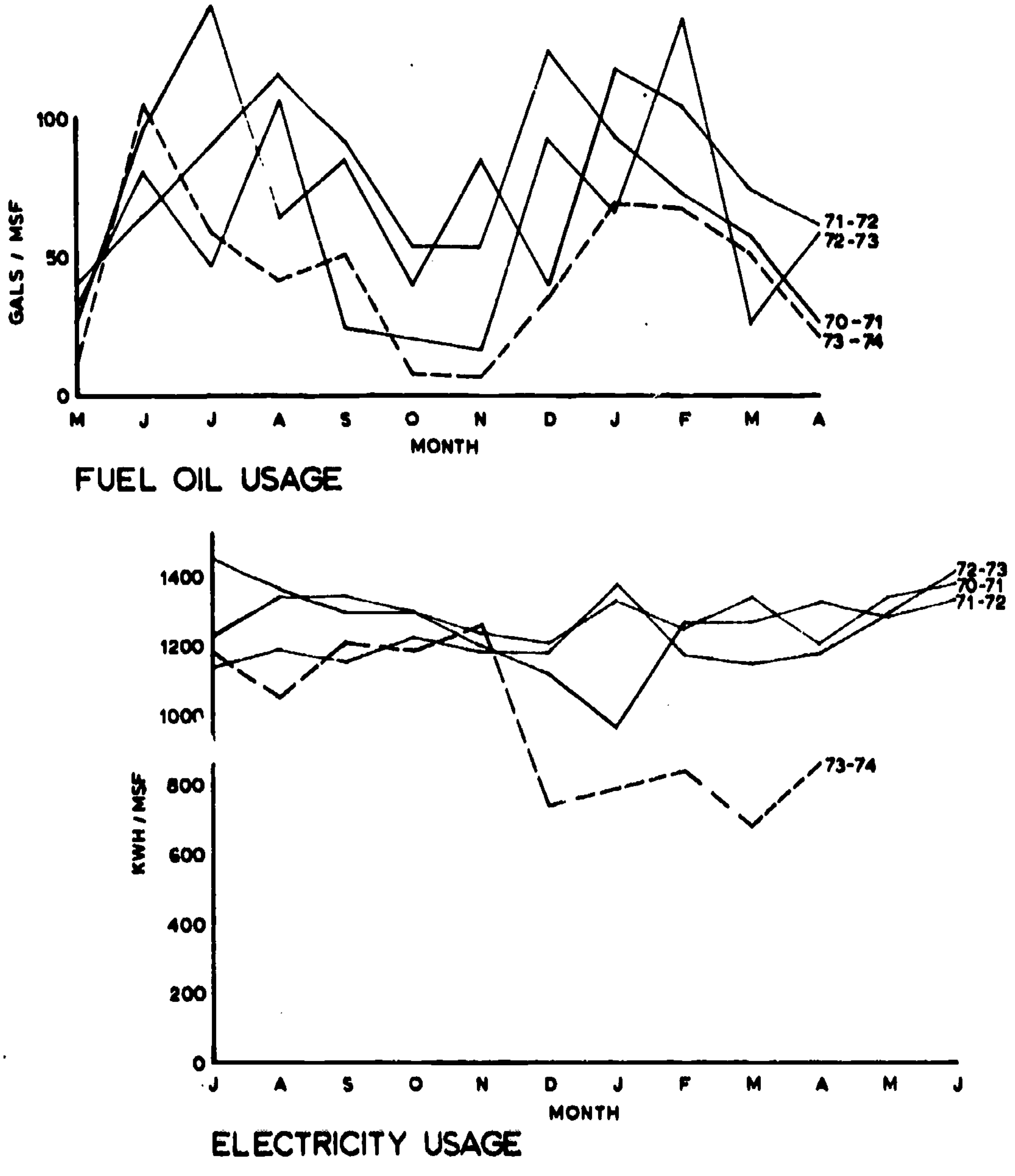
Type: unit ventilators & fan coils
Type of Exhaust System: central fan
Cfm/Typical Classrm: 550
Air-Conditioning: absorption type

	Gymnasium	Auditorium
CFM:	'6.940	13,700
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	auto	auto

ELECTRICAL

Watts/sf Typical Classrm: 5.5 Fixtures: fluorescent
Watts/sf Corridor: 2.5 Fixtures: fluorescent
Total Fan H.P.: 80
Total Pump H.P.: 120
Total Refrigeration H.P.: none
Electric Kitchen: yes

FIGURE f-3/7:
SCHOOL NO. 3



SCHOOL No. 3: INTERMEDIATE SCHOOL, MANHATTAN

SIZE: 170 MSF
YEAR OF COMPLETION: 1966

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FIGURE f-3/8:
SCHOOL NO.3

f-3/13
Fuel and
Electricity Use

SCHOOL NO. 3: INTERMEDIATE SCHOOL
MANHATTAN

SIZE: 170 MSF
YEAR OF COMPLETION: 1966

	FUEL OIL USAGE (GAL TOTAL) 70-71	71-72	72-73	73-74	FUEL OIL USAGE (GAL/MSF) 70-71	71-72	72-73	73-74
MAY	6,864	4,965	5,165	2,000	40.38	29.21	30.38	11.76
JUNE		16,178	13,680	17,109		95.16	80.47	100.64
JULY		24,000	8,014	9,992		141.48	47.14	58.78
AUG	19,884	11,000	17,957	7,236	116.96	64.71	105.63	42.56
SEPT	15,653	14,582	4,188	8,851	92.08	85.78	24.64	52.06
OCT	9,268	6,992		1,352	54.52	41.13		7.95
NOV	9,268	14,300	12,797	1,152	54.52	84.12	16.45	6.77
DEC	20,808	6,924	15,609	6,250	122.40	40.73	91.82	36.76
JAN	16,113	20,000	11,214	11,566	94.78	117.65	65.96	68.03
FEB	12,432	17,764	23,018	11,481	73.13	104.49	135.40	67.53
MAR	10,018	12,538	4,530	10,488	58.93	73.75	26.65	61.69
APR	4,500	10,500	10,000	3,607	26.47	61.76	58.82	21.22

	ELECTRICITY USAGE (KWH TOTAL) 70-71	71-72	72-73	73-74	ELECTRICITY USAGE (KWH/MSF) 70-71	71-72	72-73	73-74	ELECTRICITY DEMAND 70-71	71-72	72-73	73-74
JULY	210,000	246,000	193,200	199,200	1235	1447	1136	1172	372	420	396	396
AUG	226,000	231,600	202,800	178,800	1334	1362	1193	1052		372	408	360
SEPT	226,800	219,600	196,800	204,800	1334	1292	1158	1205	996	444	468	432
OCT	219,600	219,600	208,800	201,600	1292	1292	1228	1186	336	480	444	432
NOV	211,200	204,000	202,800	213,600	1242	1200	1193	1256	444	468	456	432
DEC	206,400	219,600	202,800	124,800	1214	1292	1193	734	432	456	420	420
JAN	225,600	190,800	236,400	135,600	1327	1122	1391	798	432	420	444	420
FEB	212,400	164,400	199,200	142,800	1249	967	1172	840	444	456	432	284
MAR	228,000	216,000	196,800	115,200	1341	1271	1158	678	444	432	432	396
APR	205,200	225,600	201,600	146,400	1207	1327	1186	801	444	456	432	324
MAY	228,000	218,400	219,600		1341	1285	1292		456	492	444	
JUNE	235,000	229,200	240,000		1382	1348	1412		480	456	420	

FIGURE f-3/8:
SCHOOL NO. 3

f-3/15
Fuel and
Electricity Use

SCHOOL NO. 4: HIGH SCHOOL, BROOKLYN
Year of Completion: 1958

BUILDING DESCRIPTION

Size: 300 msf
Floor to Floor Height: 11'-4"
Type of Construction: reinf. conc./waffle slab foors
Skin: 4" brick, 2" air, 6" block
No. of Levels: 3
Ratio: Window Area to Skin Area of Typical
Classroom Elevation: 56%
Ratio: Window Area to Typical Classroom Area:
Ceiling Height of Typical Classroom: 8'-0"
Roof Insulation:

BOILER PLANT

No. of Boilers: 4
Burner Capacity: 60 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

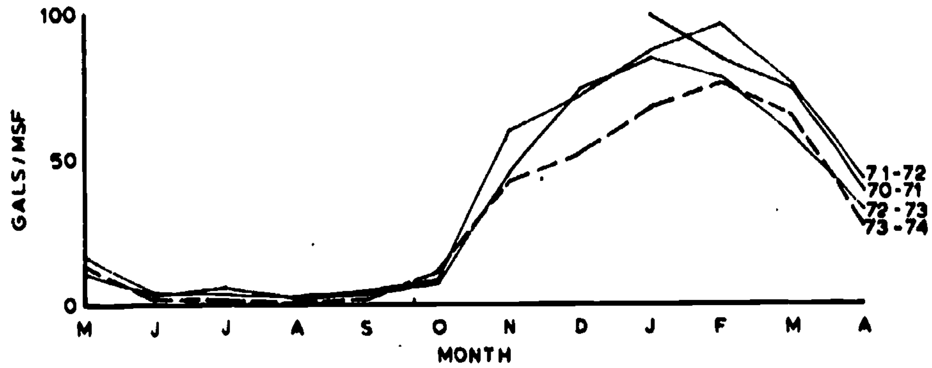
Type: open window
Type of Exhaust System: stack
Cfm/Typical Classroom: 560
Air-Conditoning: none

	Gymnasium	Auditorium
CFM:	21,600	33,000
%Outside Air:	100	100
Recirculation:	yes	yes
Controls	manual	manual

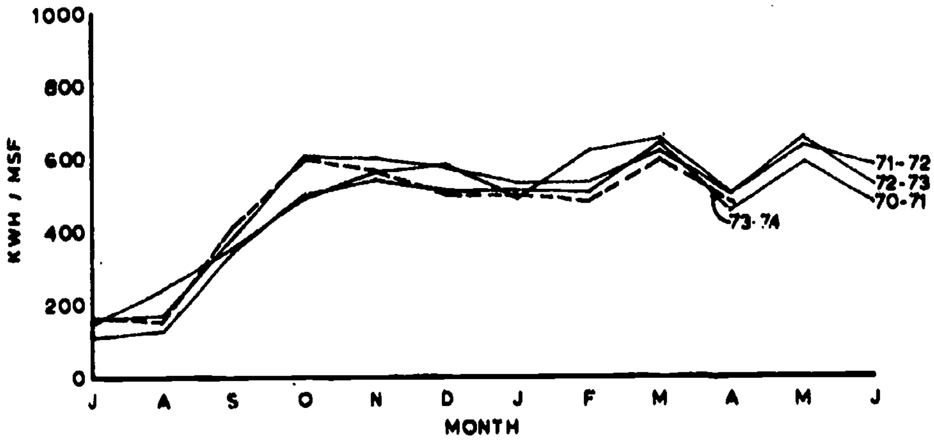
ELECTRICAL

Watts/sf Typical Classroom: Fixtures:
Watts/sf Corridor: Fixtures:
Total Fan H.P.: 80
Total Pump H.P.:
Total Refrigeration H.P.:
Electric Kitchen: yes

FIGURE f-3/9:
SCHOOL NO. 4



FUEL OIL USAGE



ELECTRICITY USAGE

FIGURE f-3/10:
SCHOOL NO. 4

SCHOOL No. 4: HIGH SCHOOL, BROOKLYN
SIZE: 300 MSF
YEAR OF COMPLETION: 1958

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SCHOOL NO. 4: HIGH SCHOOL
BROOKLYN

SIZE: 300 MSF
YEAR OF COMPLETION: 1958

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY		4,745	3,100	3,669
JUNE		1,000	900	700
JULY		1,000	1,609	600
AUG		600	500	400
SEPT		1,200	1,300	600
OCT		2,500		3,500
NOV		17,791	16,581	12,400
DEC		21,436	22,159	15,277
JAN	29,407	25,804	25,433	20,180
FEB	25,108	28,509	23,230	21,300
MAR	22,155	22,214	17,329	19,295
APR	11,420	12,837	9,653	8,000

FUEL OIL USAGE (GAL/MSF)

	70-71	71-72	72-73	73-74
MAY		15.82	10.33	12.23
JUNE		3.33	3.00	2.33
JULY		3.33	5.36	2.00
AUG		2.00	1.67	1.33
SEPT		4.00	4.33	2.00
OCT		8.33		11.66
NOV		59.30	55.27	41.33
DEC		71.45	73.89	50.92
JAN	98.02	86.01	84.78	67.26
FEB	83.69	95.03	77.43	71.00
MAR	73.85	74.05	57.76	64.32
APR	38.07	42.79	32.18	26.67

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	33,600	45,600	48,000	48,000
AUG	37,200	66,000	48,000	45,600
SEPT	105,600	106,800	118,800	121,200
OCT	148,800	147,700	182,400	181,204
NOV	164,400	169,200	181,200	169,200
DEC		174,000	172,800	138,000
JAN	307,200	164,400	158,400	136,800
FEB	151,200	187,200	158,400	144,000
MAR	192,000	195,600	189,600	176,400
APR	135,600	150,000	150,000	142,800
MAY	177,600	189,600	195,600	
JUNE	142,800	172,800	156,000	

ELECTRICITY USAGE (KWH/MSF)

	70-71	71-72	72-73	73-74
JULY	112	152	160	160
AUG	124	220	160	152
SEPT	352	356	396	404
OCT	496	492	608	604
NOV	548	564	604	564
DEC		580	576	460
JAN	1024	548	528	456
FEB	504	624	528	480
MAR	640	652	632	508
APR	452	500	500	476
MAY	592	632	652	
JUNE	476	576	520	

ELECTRICITY DEMAND

	70-71	71-72	72-73	73-74
JULY	156	204	288	
AUG	168	264	192	
SEPT	552	528	540	
OCT	552	576	588	
NOV	576	564	564	
DEC		588	588	
JAN	152	564	552	
FEB	588	564	588	
MAR	564	552	588	
APR	576	552	588	564
MAY	600	528	600	
JUNE	540	552	576	

FIGURE f-3/11:
SCHOOL NO. 4

SCHOOL NO. 5: HIGH SCHOOL, QUEENS
Year of Completion: 1955

BUILDING DESCRIPTION

Size: 311 msf
Floor to Floor Height: 10' 8 5/8"
Type of Construction: reinf. conc.
Skin: 4" brick, 2" air, 6" block
No. of Levels: 3
Ratio: Window Area to Skin Area of Typical Classroom Elevation: 39%
Ratio: Window Area to Typical Classroom Area: 19%
Ceiling Height of Typical Classroom: 10' -8"
Roof Insulation:

BOILER PLANT

No. of Boilers: 4
Burner Capacity: 65 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

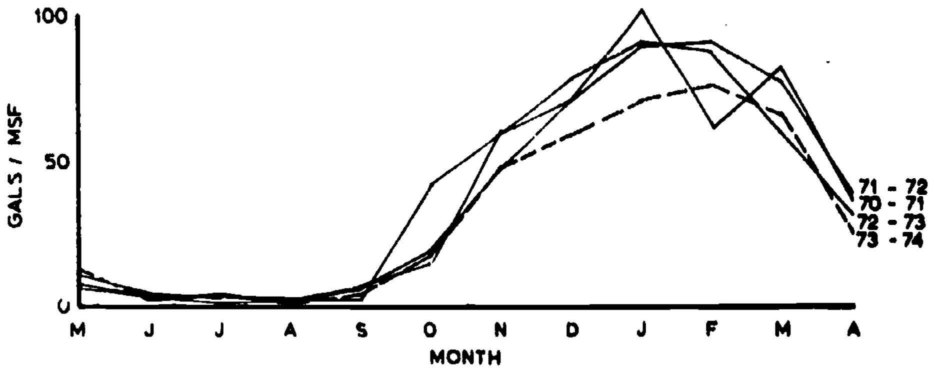
Type: open window
Type of Exhaust System: central fan
Cfm/Typical Classrm: 560
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	32,500	38,750
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	manual	manual

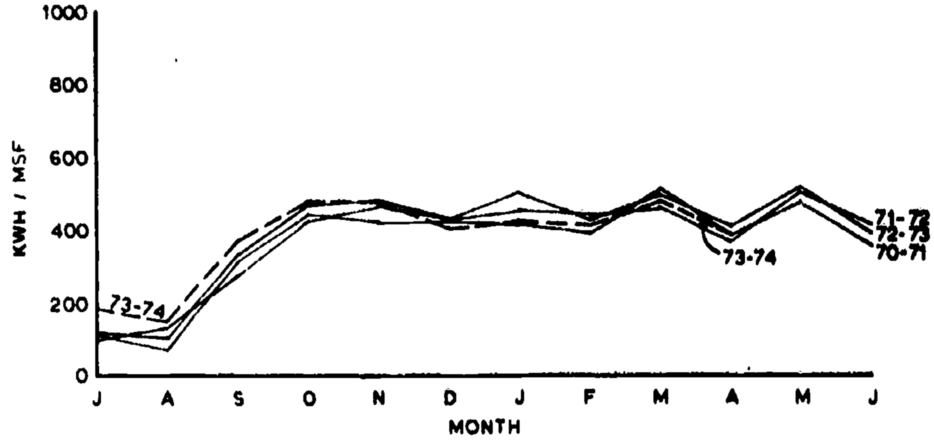
ELECTRICAL

Watts/sf Typical Classroom: 2.5 Fixtures: fluorescent
Watts/sf Corridor: 1 Fixtures: incandescent
Total Fan H.P.: 135
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen: yes

FIGURE f-3/12:
SCHOOL NO. 5



FUEL OIL USAGE



ELECTRICITY USAGE

FIGURE f-3/13:
SCHOOL NO. 5

SCHOOL No. 5: HIGH SCHOOL, QUEENS

SIZE: 311 MSF
YEAR OF COMPLETION: 1955

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SCHOOL NO. 5: HIGH SCHOOL
QUEENS

SIZE: 311 MSF

YEAR OF COMPLETION: 1955

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY	2,300	3,200	2,200	3,500
JUNE		1,300	1,200	900
JULY		700	700	800
AUG	400	400	500	0
SEPT	1,600	1,700	700	1,200
OCT	6,100	4,700	13,100	5,200
NOV	15,500	19,000	18,900	15,500
DEC	22,500	21,900	24,300	18,200
JAN	31,800	28,300	28,500	22,300
FEB	25,100	28,500	27,100	24,200
MAR	25,600	24,000	18,500	20,800
APR	11,100	12,400	9,800	8,000

FUEL OIL USAGE (GAL/MSF)

	70-71	71-72	72-73	73-74
MAY	7.40	10.29	7.07	11.25
JUNE		4.18	3.86	2.89
JULY	1.29	2.25	2.25	2.57
AUG	1.29	1.29	1.61	0
SEPT	5.14	5.47	2.24	3.86
OCT	19.61	15.11	42.12	16.72
NOV	49.84	61.09	60.77	49.84
DEC	72.35	70.42	78.14	58.52
JAN	102.25	91.00	91.64	71.70
FEB	60.71	91.64	87.14	77.81
MAR	82.32	77.17	59.49	66.88
APR	35.69	39.87	31.51	25.72

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	46,080	45,060	48,300	55,500
AUG	22,920	40,200	31,080	49,260
SEPT	99,120	86,820	102,660	114,720
OCT	136,800	132,660	147,540	148,860
NOV	129,240	145,560	149,640	148,500
DEC	131,040	135,960	133,740	125,400
JAN	126,960	141,180	154,560	130,680
FEB	121,800	136,800	133,260	124,800
MAR	159,660	141,840	153,180	147,120
APR	116,760	113,520	124,560	117,300
MAY	148,260	153,120	161,040	
JUNE	111,600	126,420	121,980	

ELECTRICITY USAGE (KWH/MSF)

	70-71	71-72	72-73	73-74
JULY	148	145	155	178
AUG	74	129	100	158
SEPT	319	279	330	369
OCT	440	427	474	479
NOV	416	468	481	477
DEC	421	437	430	403
JAN	408	454	497	420
FEB	392	440	428	401
MAR	513	456	493	473
APR	375	365	401	377
MAY	477	492	518	
JUNE	359	406	392	

ELECTRICITY DEMAND

	70-71	71-72	72-73	73-74
JULY	112	180	232	200
AUG	68	108	100	128
SEPT	500	476	496	500
OCT	500	496	492	516
NOV	500	500	512	508
DEC	516	496	520	496
JAN	496	504	512	500
FEB	496	496	524	492
MAR	500	592	520	500
APR	504	500	504	500
MAY	508	496	520	
JUNE	472	504	436	

FIGURE f-3/14:
SCHOOL NO. 5

f-3/23
Fuel and
Electricity Use

SCHOOL NO. 6: HIGH SCHOOL, QUEENS
Year of Completion: 1966

BUILDING DESCRIPTION:

Size: 284 msf
Floor to Floor Height: 12' -8¼" avg.
Type of Construction: steel, conc. floor slabs
Skin: 4" brick, 2" air, 6" block
No. of Levels: 3
Ratio: Window Area to Skin Area of Typical Classroom Elevation: 29%
Ratio: Window Area to Typical Classroom Area: 14%
Ceiling Height of Typical Classroom: 9' -0"
Roof Insulation:

BOILER PLANT

No. of Boilers: 4
Burner Capacity: 99 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

Type: open window
Type of Exhaust System: central fan
Cfm/Typical Classroom: 560
Air-Conditioning: electric centrifugal

	Gymnasium	Auditorium
CFM:	45,000	23,600
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	auto	auto

ELECTRICAL

Watts/sf Typical Classrm: 2.3 Fixtures: fluorescent
Watts/sf Corridor: 1 Fixtures: fluorescent
Total Fan H.P.: 230
Total Pump H.P.: 40
Total Refrigeration H.P.: 260
Electric Kitchen:

FIGURE f-3/15:
SCHOOL NO. 6

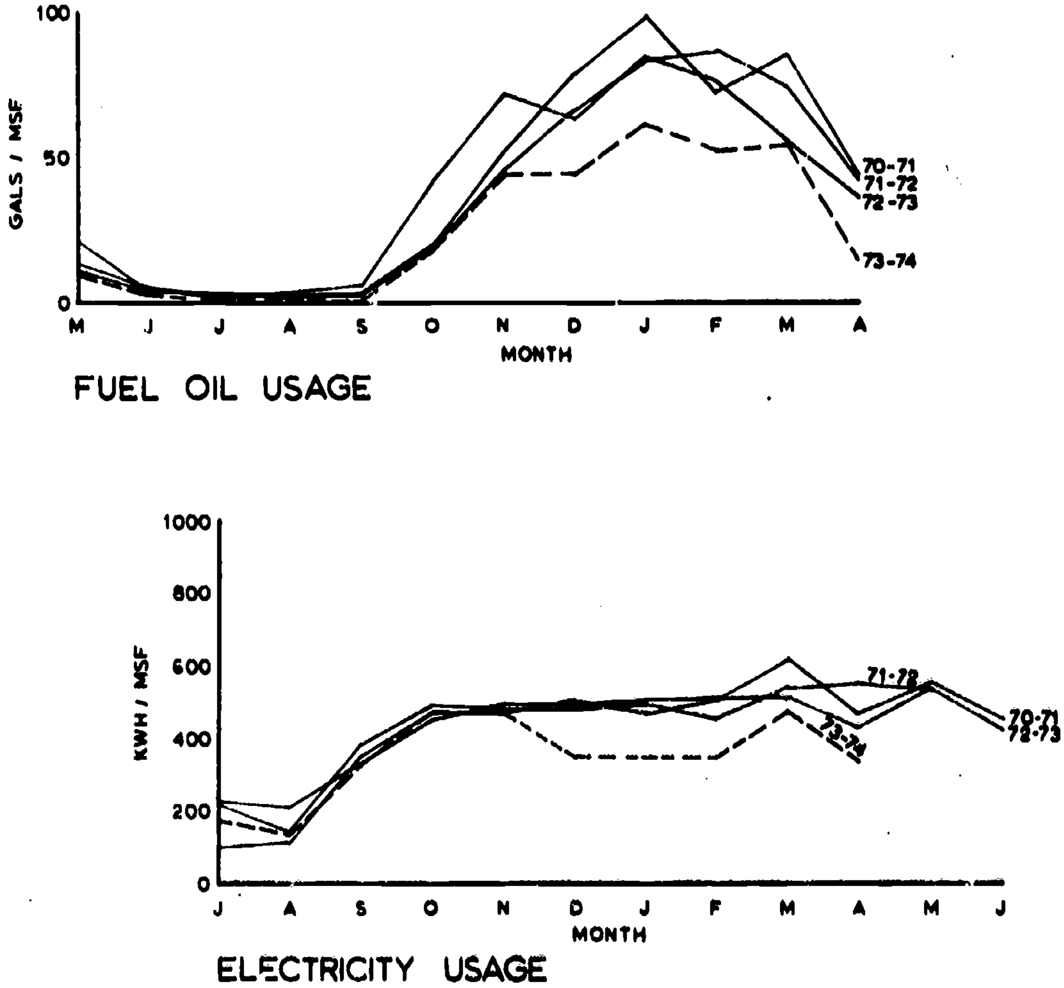


FIGURE f-3/16:
SCHOOL NO. 6

SCHOOL No. 6 : HIGH SCHOOL, QUEENS

SIZE: 284 MSF
YEAR OF COMPLETION: 1966

RGS&A-74

SCHOOL NO.6: HIGH SCHOOL
QUEENS

SIZE: 284 MSF
YEAR OF COMPLETION: 1966

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY	2,845	3,862	5,945	2,369
JUNE	961	999	969	792
JULY	832	716	346	346
AUG	636	577	1,098	202
SEPT	641	571	1,607	160
OCT	5,530	5,482	11,945	5,136
NOV	14,518	12,783	20,430	12,539
DEC	22,563	18,908	17,892	12,672
JAN	27,785	23,548	23,840	17,222
FEB	20,916	24,623	22,066	14,551
MAR	24,336	21,025	15,567	15,444
APR	12,281	12,094	10,201	3,862

FUEL OIL USAGE (GAL/MSF)

70-71	71-72	72-73	73-74
10.02	13.60	20.93	8.34
3.38	3.52	3.41	2.79
2.93	2.52	1.22	1.22
2.24	2.03	3.87	0.71
2.26	2.01	5.66	0.56
19.47	19.30	42.06	18.08
51.12	45.01	71.94	44.15
79.45	66.55	63.00	44.61
97.83	82.92	83.94	60.64
73.65	86.70	77.70	51.23
85.69	74.03	54.81	54.38
43.24	42.58	35.92	13.60

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	27,600	63,600	57,600	45,600
AUG	31,200	58,800	42,000	37,200
SEPT	102,000	100,800	108,000	98,400
OCT	132,000	128,400	136,800	130,800
NOV	130,800	136,800	133,200	133,200
DEC	141,600	136,800	135,600	99,600
JAN	133,200	144,000	138,000	98,400
FEB	140,400	141,600	126,000	98,400
MAR	174,000	146,400	152,400	130,800
APR	132,000	121,200	124,800	93,600
MAY	157,200	151,200	151,200	
JUNE	129,600		115,200	

ELECTRICITY USAGE (KWH/MSF)

70-71	71-72	72-73	73-74
97	224	203	161
110	207	148	131
359	355	380	346
465	452	482	461
461	485	469	469
499	485	477	351
469	507	486	346
494	499	444	346
613	515	537	461
465	427	439	330
554	532	532	
456		406	

ELECTRICITY DEMAND

70-71	71-72	72-73	73-74
228	312	384	324
300	336	324	192
684	636	706	564
600	564	624	588
612	516	552	564
588	576	576	564
600	600	612	552
612	576	588	540
600	588	552	540
588	576	538	576
684	636	600	
708		648	

FIGURE f-3/17:
SCHOOL NO. 6

f-3/27
Fuel and
Electricity Use

SCHOOL NO. 7: HIGH SCHOOL, QUEENS
Year of Completion: 1965

BUILDING DESCRIPTION

Size: 254 msf
Floor to Floor Height: 10' -0"
Type of Construction: reinf. conc.
Skin: 4" brick, 2" air, 6" block
No. of Levels: 3
Ratio: Window Area to Skin Area of Typical Classroom Elevation: 58%
Ratio: Window Area to Typical Classroom Area: 19%
Ceiling Height of Typical Classroom: 9' -0"
Roof Insulation: 1"

BOILER PLANT

No. of Boilers: 4
Burner Capacity: 113 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

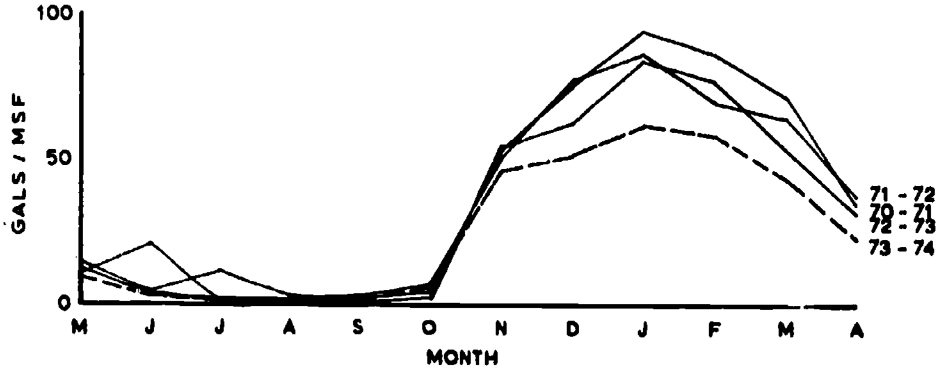
Type: open window
Type of Exhaust System: central fan
Cfm/Typical Classroom: 540
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	51,000	36,000
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	auto	auto

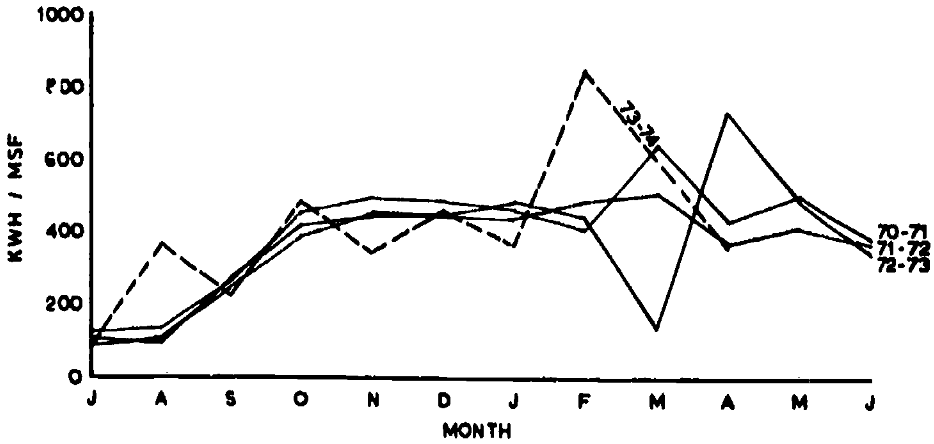
ELECTRICAL

Watts/sf Typical Classroom: 2.75 Fixtures: fluorescent
Watts/sf Corridor: 0.85 Fixtures: fluorescent
Total Fan H.P.: 125
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen:

FIGURE f-3/18:
SCHOOL NO. 7



FUEL OIL USAGE



ELECTRICITY USAGE

FIGURE f-3/19:
SCHOOL NO. 7

SCHOOL No. 7 : HIGH SCHOOL, QUEENS

SIZE : 254 MSF
YEAR OF CONSTRUCTION : 1965

RGS & A -74

SCHOOL NO. 7: HIGH SCHOOL
QUEENS

SIZE: 254 MSF

YEAR OF COMPLETION: 1965

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY	2,792	3,030	3,597	2,337
JUNE	5,221	807	1,115	801
JULY			3,187	204
AUG	180	437		409
SEPT	500	768	369	632
OCT	1,109	2,024	455	1,327
NOV	13,298	12,849	13,845	11,672
DEC	19,131	19,231	15,973	12,779
JAN	23,776	22,302	21,216	15,862
FEB	21,660	17,700	19,112	14,798
MAR	17,875	16,291	13,595	11,233
APR	8,701	9,559	8,055	5,627

FUEL OIL USAGE (GAL/MSF)

70-71	71-72	72-73	73-74
10.99	11.93	14.16	9.20
20.56	3.18	4.39	3.15
		12.55	0.80
0.71	1.72		1.61
1.97	3.02	1.45	2.49
4.37	7.97	1.79	5.22
52.35	50.59	54.51	45.95
75.32	75.71	62.89	50.31
93.61	87.80	83.53	62.45
85.28	69.69	75.24	58.26
70.37	64.14	53.52	44.22
34.26	37.63	31.71	22.15

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	31,200	21,600	26,400	21,600
AUG	32,400	27,600	24,000	96,000
SEPT	79,200	68,400	79,200	60,000
OCT	116,400	100,800	122,400	122,400
NOV	124,800	118,800	117,600	88,800
DEC	122,400	116,400	114,000	115,200
JAN	117,600	111,600	122,400	92,400
FEB	102,000	123,600	112,800	214,800
MAR	174,000	130,800	36,000	
APR	110,400	93,600	189,600	93,600
MAY	126,000	129,600	128,400	
JUNE	98,400	96,000	91,200	

ELECTRICITY USAGE (KWH/MSF)

70-71	71-72	72-73	73-74
123	85	104	85
128	109	94	378
312	269	312	236
458	397	422	482
491	468	463	350
482	458	449	454
463	439	482	364
402	487	444	845
685	518	142	
435	369	746	368
496	510	506	
387	378	359	

ELECTRICITY DEMAND

70-71	71-72	72-73	73-74
168	132	168	228
168	120	108	268
540	504	468	156
504	492	468	768
552	504	492	480
540	492	504	456
552	480	480	420
540	504	480	420
552	504	468	
528	492	468	432
516	492	468	
504	468	456	

FIGURE f-3/20:
SCHOOL NO. 7

f-3/31
Fuel and
Electricity Use

SCHOOL NO. 8: HIGH SCHOOL, BRONX
Year of Completion: 1969

BUILDING DESCRIPTION:

Size: * 371 msf
Floor to Floor Height: 11' -0"
Type of Construction: steel, conc. floor slab
Skin: 4" brick, 2" air, 6" block
No. of Levels: 3
Ratio: Window Area to Skin Area of Typical Classroom Elevation: 50%
Ratio: Window Area to Typical Classroom Area: 19%
Ceiling Height of Typical Classroom: 8' -9"
Roof Insulation: 2"

BOILER PLANT

No. of Boilers: 4
Burner Capacity: 93 gal/hr
Type of Boiler: compact
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

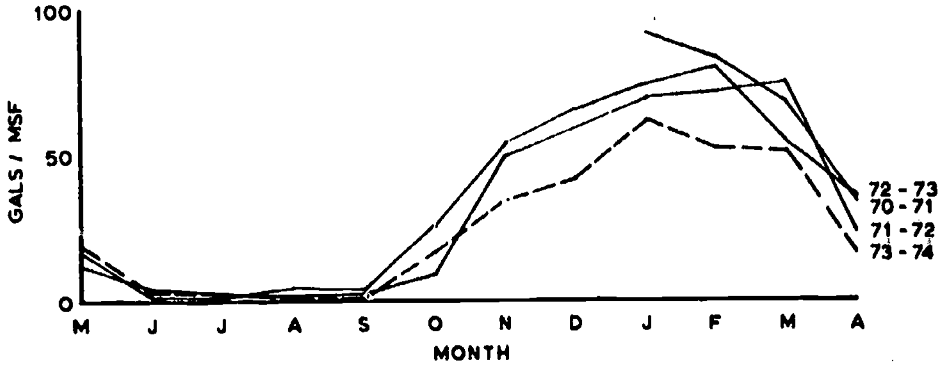
Type: open window
Type of Exhaust System: combination central fan & stack
Cfm/Typical Classroom: 560
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	52,000	33,600
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	auto	auto

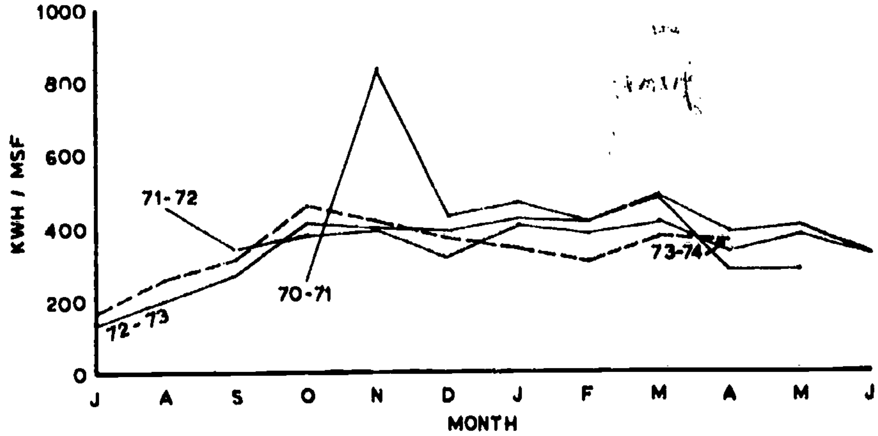
ELECTRICAL

Watts/sf Typical Classroom: 2.3 Fixtures: fluorescent
Watts/sf Corridor: 1 Fixtures: fluorescent
Total Fan H.P.: 130
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen: yes

FIGURE f-3/21:
SCHOOL NO. 8



FUEL OIL USAGE



ELECTRICITY USAGE

FIGURE f-3/22:
SCHOOL NO. 8

SCHOOL No. 8: HIGH SCHOOL, BRONX

SIZE: 371 MSF
YEAR OF COMPLETION: 1969

RGS&A-74

SCHOOL NO. 8: HIGH SCHOOL
BRONX

SIZE: 371 MSF
YEAR OF COMPLETION: 1969

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY		4,600	5,650	6,657
JUNE		1,400	300	862
JULY		400	200	800
AUG		200	1,500	100
SEPT		800	1,113	100
OCT		3,500	11,348	5,800
NOV		18,400	20,383	12,458
DEC		21,900	24,411	15,548
JAN	33,748	25,600	27,816	22,844
FEB	31,400	27,100	29,872	19,164
MAR	25,645	27,900	20,132	19,123
APR	12,300	8,500	12,686	7,948

FUEL OIL USAGE (GAL/MSF)

	70-71	71-72	72-73	73-74
MAY		12.40	15.23	17.94
JUNE		3.77	0.81	2.32
JULY		1.08	0.54	2.16
AUG		0.54	4.04	0.27
SEPT		2.16	3.00	0.27
OCT		9.43	30.59	15.63
NOV		49.60	54.94	33.58
DEC		59.03	65.80	41.90
JAN	90.96	69.00	74.98	61.57
FEB	84.16	73.05	80.52	51.65
MAR	69.12	75.20	54.26	51.54
APR	33.15	22.91	34.19	21.42

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY			48,000	60,000
AUG		168,000	74,400	97,200
SEPT		127,200	103,200	103,200
OCT	102,000	140,400	152,400	171,600
NOV	308,400	147,600	148,800	158,400
DEC	162,000		146,400	136,800
JAN	172,800	267,600	156,000	126,000
FEB	156,000	141,600	154,800	116,400
MAR	181,200	152,400	178,800	139,200
APR	141,600	121,200		133,200
MAY	150,000	139,200	230,400	
JUNE	120,000	120,00		

ELECTRICITY USAGE (KWH/MSF)

	70-71	71-72	72-73	73-74
JULY			129	162
AUG		453	201	262
SEPT		343	278	278
OCT	275	373	411	463
NOV	831	398	401	427
DEC	437		395	369
JAN	466	721	420	340
FEB	420	382	417	314
MAR	488	411	482	375
APR	382	327		359
MAY	404	375	621	
JUNE	323	323		

ELECTRICITY DEMAND

	70-71	71-72	72-73	73-74
JULY			456	252
AUG		516	264	252
SEPT		600	588	660
OCT	454.4	636	672	684
NOV	1041.6	684	684	660
DEC	552		696	624
JAN	564	320	708	610
FEB	600	684	660	624
MAR	576	696	660	612
APR	540	672		610
MAY	540	648	332	
JUNE	492	552		

FIGURE f-3/23:
SCHOOL NO. 8

SCHOOL NO. 9: HIGH SCHOOL, QUEENS
Year of Completion: 1964

BUILDING DESCRIPTION

Size: 254 msf
Floor to Floor Height: 10' -0"
Type of Construction: reinf. conc.
Skin: 4" brick, 2" air, 6" block
No. of Levels: 3
Ratio: Window Area to Skin Area of Typical Classroom Elevation: 50%
Ratio: Window Area to Typical Classroom: 9' -3"
Roof Insulation: conc. topping

BOILER PLANT

No. of Boilers: 4
Burner Capacity: 113 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

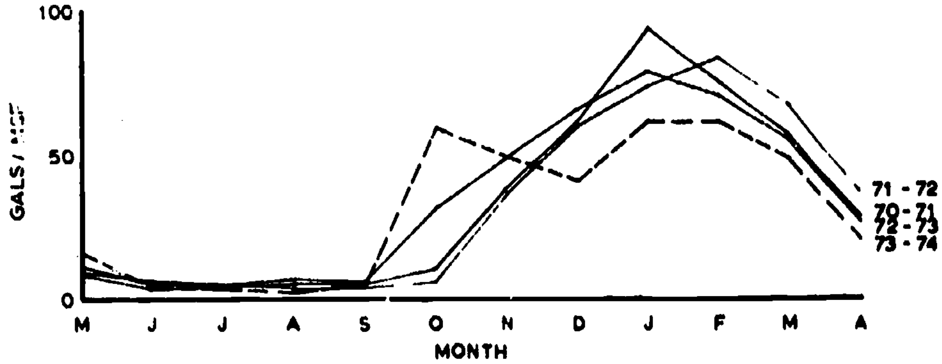
Type: open window
Type of Exhaust System: central fan
Cfm/Typical Classroom: 540
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	51,000	36,000
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	manual	manual

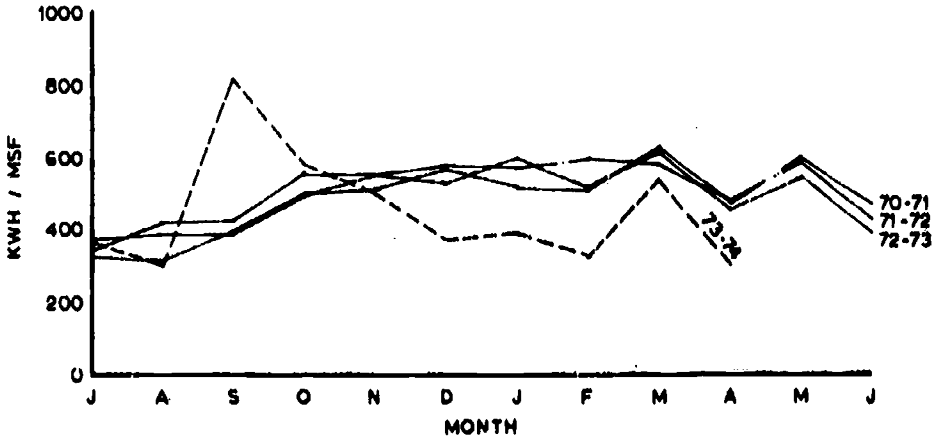
ELECTRICAL

Watts/sf Typical Classroom: 2.85 Fixtures: fluorescent
Watts/sf Corridor: 0.85 Fixtures: fluorescent
Total Fan H.P.: 125
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen: yes

FIGURE f-3/24: SCHOOL NO. 9



FUEL OIL USAGE



ELECTRICITY USAGE

FIGURE f-3/25:
SCHOOL NO. 9

SCHOOL No. 9 : HIGH SCHOOL, QUEENS

SIZE: 254 MSF
YEAR OF COMPLETION: 1964

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SCHOOL NO. 9: HIGH SCHOOL
QUEENS

SIZE: 254 MFS
YEAR OF COMPLETION: 1964

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY	1,850	2,303	3,000	3,875
JUNE	1,050	1,700	1,530	1,200
JULY			1,500	1,100
AUG	1,316	1,000	1,819	700
SEPT	1,300	1,120	1,550	1,300
OCT	3,016	1,550	8.136	15,002
NOV	9,866	9,290	12,501	12,565
DEC	15,932	15,002	16,612	10,510
JAN	23,908	18,786	20,038	15,440
FEB	19,059	21,317	17,914	15,338
MAR	14,432	17,092	14,238	12,400
APR	7,548	9,632	7,015	5,101

FUEL OIL USAGE (GAL/MSF)

	70-71	71-72	72-73	73-74
MAY	7.28	9.06	11.81	15.25
JUNE	4.13	6.69	5.91	4.72
JULY			5.91	4.33
AUG	5.18	3.94	7.16	2.75
SEPT	5.12	4.41	6.10	5.19
OCT	11.87	6.10	32.03	59.06
NOV	38.84	36.57	49.22	49.83
DEC	62.72	59.06	65.40	41.38
JAN	94.13	73.96	78.89	60.79
FEB	75.04	83.93	70.53	60.38
MAR	56.82	67.29	56.06	48.82
APR	29.72	37.92	27.62	20.08

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	81,600	94,800	87,600	92,400
AUG	80,400	98,400	105,600	76,800
SEPT	100,800	98,400	108,000	206,400
OCT	124,800	124,800	140,400	146,400
NOV	127,200	140,400	140,400	124,800
DEC	142,800	146,400	133,200	93,600
JAN	130,800	145,200	151,200	98,400
FEB	129,600	151,200	130,800	81,600
MAR	157,200	146,400	154,800	133,200
APR	120,000	121,200	112,800	75,600
MAY	151,200	147,600	135,600	
JUNE	117,600	133,200	38,400	

ELECTRICITY USAGE (KWH/MSF)

	70-71	71-72	72-73	73-74
JULY	321	373	345	364
AUG	317	387	416	302
SEPT	397	387	423	813
OCT	491	491	553	576
NOV	501	553	553	491
DEC	562	576	524	368
JAN	515	576	595	387
FEB	510	595	515	321
MAR	619	576	609	524
APR	472	477	454	298
MAY	595	581	534	
JUNE	463	524	387	

ELECTRICITY DEMAND

	70-71	71-72	72-73	73-74
JULY	296	360	312	304
AUG	304	328	356	272
SEPT	496	496	512	480
OCT	496	407	529	512
NOV	520	536	528	520
DEC	520	536	520	480
JAN	520	512	528	480
FEB	488	536	520	472
MAR	504	512	520	488
APR	488	504	504	464
MAY	488	528	496	
JUNE	496	520	488	

FIGURE f-3/26:
SCHOOL NO. 9

f-3/39
Fuel and
Electricity Use

SCHOOL NO. 10: HIGH SCHOOL, BROOKLYN
Year of Completion: 1969

BUILDING DESCRIPTION

Size: 404 msf
Floor to Floor Height: 10' -5½"
Type of Construction: reinf. conc./conc. waffle slabs
Skin: 4" brick, 2" air, 6" block
No. of Levels: 4
Ratio: Window Area to Skin Area of Typical
Classroom Elevation: 37%
Ratio: Window Area to Typical Classroom Area: 14%
Ceiling Height of Typical Classroom: 10' -0"
Roof Insulation: 2"

BOILER PLANT

No. of Boilers: 4
Burner Capacity: 115 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Gneration: heat exchanger

VENTILATION SYSTEM

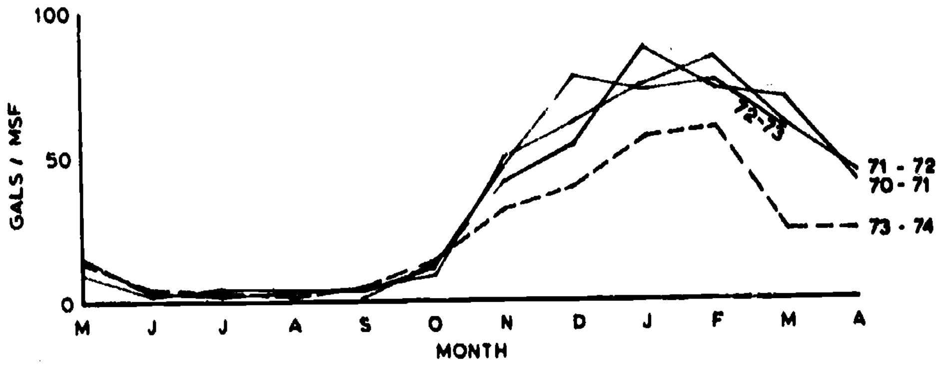
Type: open window
Type of Exhaust System: central fan
Cfm/Typical Classroom: 560
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	77,000	39,500
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	auto	auto

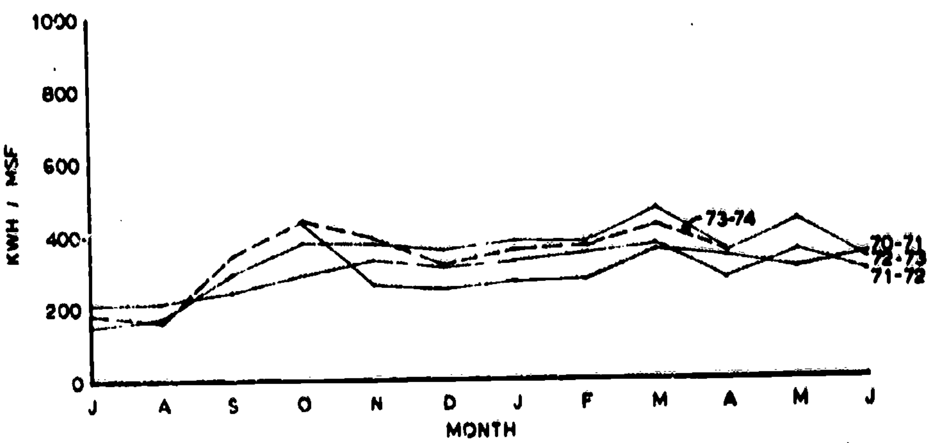
ELECTRICAL

Watts/sf Typical Classrm: 2 — Fixtures: fluorescent
Watts/sf Corridor: 0.8 — Fixtures: fluorescent
Total Fan H.P.: 220
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen: Yes

FIGURE f-3/27:
SCHOOL NO. 10



FUEL OIL USAGE



ELECTRICITY USAGE

SCHOOL No. 10: HIGH SCHOOL, BROOKLYN

SIZE: 404 MSF
YEAR OF COMPLETION: 1969

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FIGURE f-3/28:
SCHOOL NO. 10

SCHOOL NO. 10: HIGH SCHOOL
BROOKLYN

SIZE: 404 MSF
YEAR OF COMPLETION 1969

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY		6,039	4,015	5,500
JUNE		1,220	1,025	1,523
JULY		750	1,938	1,375
AUG		1,100	1,469	550
SEPT	60	1,700	1,527	1,900
OCT	5,140	3,239		5,673
NOV	16,209	19,862	23,243	12,615
DEC	21,729	24,754	30,942	15,796
JAN	35,537	30,192	29,163	22,836
FEB	29,453	33,651	30,313	23,790
MAR	28,245	24,391	23,823	9,690
APR	16,477	17,767		9,374

FUEL OIL USAGE (GAL/MSF)

	70-71	71-72	72-73	73-74
MAY		14.95	9.94	13.61
JUNE		3.02	2.54	3.77
JULY		1.85	4.80	3.40
AUG		2.72	3.64	1.36
SEPT	0.15	4.21	3.78	4.70
OCT	12.72	8.02		14.04
NOV	40.12	49.16	57.53	31.22
DEC	53.78	61.27	76.59	39.10
JAN	87.69	74.73	72.19	56.52
FEB	72.90	83.29	75.03	58.87
MAR	[illegible]	60.37	58.97	23.99
APR	[illegible]	43.98		23.20

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY		84,000	62,400	75,600
AUG		85,200	67,200	64,800
SEPT		98,400	118,800	139,200
OCT	175,200	116,400	152,400	176,400
NOV	104,400	132,000	148,800	154,800
DEC	99,600	126,000	145,200	127,200
JAN	109,200	130,800	154,800	143,200
FEB	111,600	139,200	151,200	147,600
MAR	142,800	147,600	175,200	169,200
APR	134,400	110,400	138,000	140,400
MAY	120,000	144,000	175,200	
JUNE	134,400	117,600	132,000	

ELECTRICITY USAGE (KWH/MSF)

	70-71	71-72	72-73	73-74
JULY		208	154	187
AUG		211	166	160
SEPT		244	294	344
OCT	434	288	377	437
NOV	258	327	368	383
DEC	247	312	359	315
JAN	270	324	383	359
FEB	276	345	374	365
MAR	353	365	434	419
APR	335	273	342	348
MAY	297	356	434	
JUNE	333	291	327	

ELECTRICITY DEMAND

	70-71	71-72	72-73	73-74
JULY		384	288	192
AUG		368	272	264
SEPT			704	564
OCT	625.6		720	576
NOV	448	952	864	492
DEC	464	688	560	480
JAN	480	688	768	510
FEB	528	688	784	528
MAR	544	704	750	480
APR	528	640	704	480
MAY	576	656	736	
JUNE	544	800	736	

FIGURE f-3/29:
SCHOOL NO. 10

SCHOOL NO. 11: Intermediate School, Brooklyn
Year of Completion: 1970

BUILDING DESCRIPTION

Size: 169 msf
Floor to Floor Height: 10'-6"
Type of Construction: steel, conc. floor slab
Skin: 4" brick, 6" block, no air space
No. of Levels: 3
Ratio: Window Area to Skin Area of Typical
Classroom Elevation: 41%
Ratio: Window Area to Typical Classroom Area 15%
Ceiling Height of Typical Classroom: 10'-0"
Roof Insulation:

BOILER PLANT

No. of Boilers: 3
Burner Capacity: 65 gal/hr
Type of Loiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

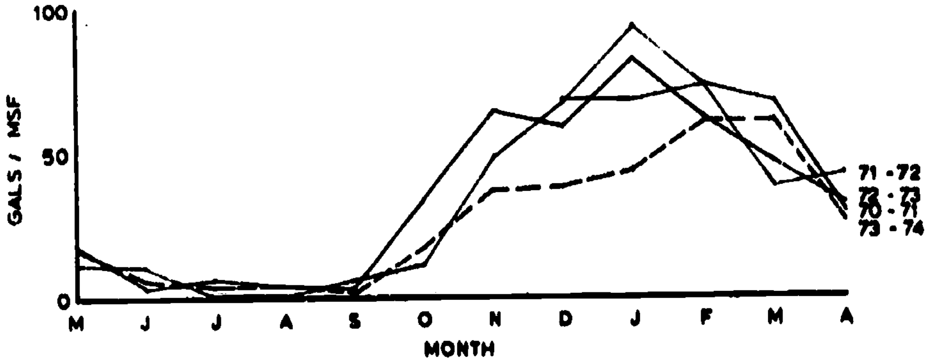
Type: open window
Type of Exhaust System: stack
Cfm/Typical Classroom: 560
Air-Conditioning:

	Gymnasium	Auditorium
CFM:	22,600	15,750
% Outside Air	100	100
Recirculation:	yes	yes
Controls:	auto	auto

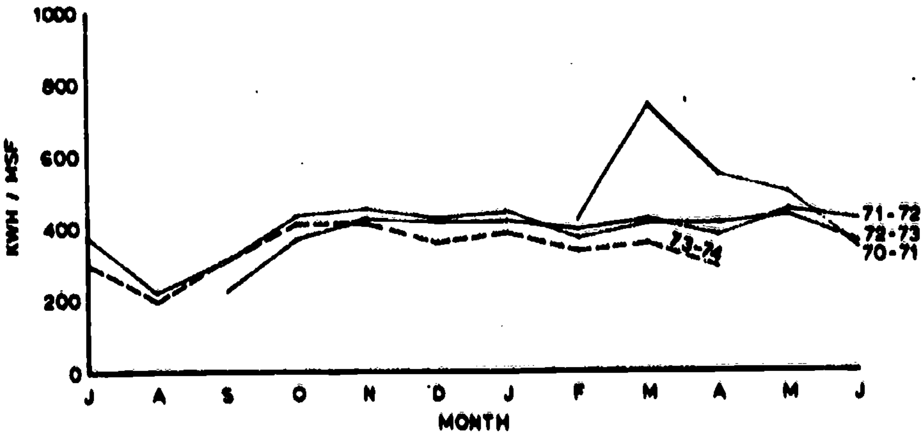
ELECTRICAL

Watts/sf Typical Classroom: Fixtures:
Watts/sf Corridor: Fixtures:
Total Fan H.P.: 52
Total Pump H.P.:
Total Refrigeration H.P.:
Electric Kitchen:

FIGURE f-3/30: SCHOOL NO. 11



FUEL OIL USAGE



ELECTRICITY USAGE

SCHOOL No. 11: INTERMEDIATE SCHOOL, BROOKLYN

SIZE: 169 MSF
YEAR OF COMPLETION: 1970

RGS 6A-74

FIGURE f-3/31:
SCHOOL NO. 11

f-3/45
Fuel and
Electricity Use

SCHOOL NO. 11: INTERMEDIATE SCHOOL
BROOKLYN

SIZE: 169 MSF
YEAR OF COMPLETION 1970

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY		2,000	2,800	2,600
JUNE		1,800	600	1,064
JULY			1,114	600
AUG			800	800
SEPT		1,00	600	457
OCT	7,200	1,870	5,800	3,600
NOV		8,134	10,860	6,300
DEC	11,562	11,162	9,892	6,523
JAN	11,495	16,000	13,873	7,600
FEB	12,335	12,335	10,600	10,523
MAR	11,435	6,337	8,033	10,500
APR	4,981	7,193	5,540	5,100

FUEL OIL USAGE (GAL/MSF)

	70-71	71-72	72-73	73-74
MAY		11.83	16.57	15.38
JUNE		10.65	3.55	6.30
JULY			6.59	3.55
AUG			4.73	4.73
SEPT		5.92	3.55	2.70
OCT	42.60	11.07	34.32	17.75
NOV		48.13	64.26	37.28
DEC	68.36	66.05	58.53	38.60
JAN	68.02	94.67	82.09	44.97
FEB	72.99	72.99	62.72	62.27
MAR	67.66	37.50	47.53	62.13
APR	29.47	42.56	32.78	30.18

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY			44,400	39,600
AUG		158,400	37,200	33,600
SEPT		37,200	52,800	52,800
OCT		61,200	73,200	68,400
NOV		70,800	75,600	68,400
DEC	182,400	69,600	72,000	60,000
JAN	194,400	69,600	74,400	63,660
FEB	68,800	67,200	61,200	55,260
MAR	123,600	70,800	68,400	60,000
APR	91,200	63,600	68,400	48,0000
MAY	82,800	74,400	73,200	
JUNE	57,600	70,800	60,000	

ELECTRICITY USAGE (KWH/MSF)

	70-71	71-72	72-73	73-74
JULY			263	234
AUG		937	220	199
SEPT		220	312	312
OCT		362	433	405
NOV		419	447	405
DEC	1079	412	426	355
JAN	1150	412	440	377
FEB	407	398	362	327
MAR	731	419	405	355
APR	540	376	405	284
MAY	490	440	433	
JUNE	341	419	355	

ELECTRICITY DEMAND

	70-71	71-72	72-73	73-74
JULY			216	120
AUG		144	132	108
SEPT		396	276	
OCT		288	300	280
NOV		276	288	300
DEC	562	276	288	276
JAN	600	264	300	264
FEB	300	264	264	252
MAR	276	288	288	280
APR	288	288	264	252
MAY	276	300	288	
JUNE	240	276	252	

FIGURE f-3/32:
SCHOOL NO. 11

SCHOOL NO. 12: High School, Brooklyn
Year of Completion: 1969

BUILDING DESCRIPTION

Size: 282 msf
Floor to Floor Height: 11'-9"
Type of Construction: steel, conc. Floor slab
Skin: 10 1/2" masonry, 2" air, 3" plaster
No. of Levels: 3
Ratio: Window Area to Skin Area of Typical
Classroom Elevation: 49%
Ratio: Window Area to Typical Classroom Area: 21%
Ceiling Height of Typical Classroom: 11'-3"
Roof Insulation: 2"

BOILER PLANT

No. of Boilers: 4
Burner Capacity: 93 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

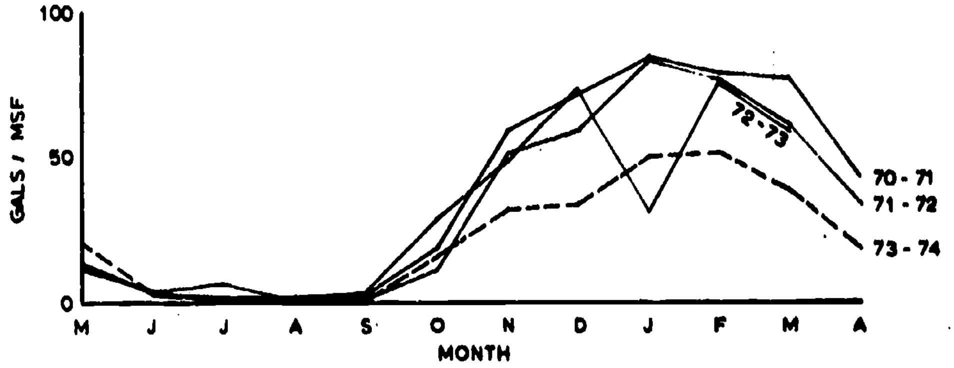
Type: open window
Type of Exhaust System: centra; fan
Cfm/Typical Classroom 560
Air-Conditioning: none

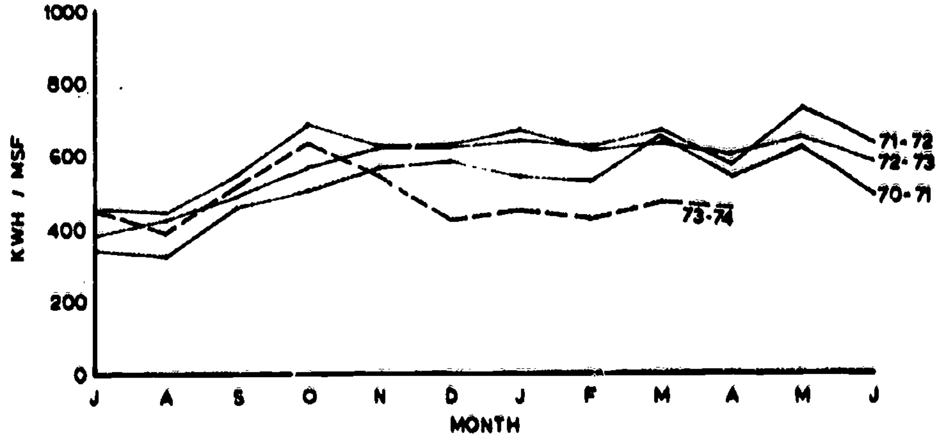
	Gymnasium	Auditorium
CFM:	56,150	35,400
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	auto	auto

ELECTRICAL

Watts/sf Typical Classroom: 2 Fixtures: fluorescent
Watts/sf Corridor: 1.5 Fixtures: fluorescent
Total Fan H.P.: 230
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen: yes

FIGURE f-3/33
SCHOOL NO. 12





SCHOOL No. 12 HIGH SCHOOL, BROOKLYN
SIZE: 282 MSF
YEAR OF COMPLETION: 1969

RGS & A-74

FIGURE f-3/34:
SCHOOL NO. 12

SCHOOL NO. 12: HIGH SCHOOL
BROOKLYN

SIZE: 282 MSF
YEAR OF COMPLETION: 1969

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY	3,719	3,707	3,370	5,817
JUNE	620	720	970	625
JULY	312	285	2,014	555
AUG	360	285	260	440
SEPT	567	550	627	398
OCT	5,435	2,974	8,437	4,555
NOV	16,599	14,602	13,620	9,022
DEC		16,461	20,860	9,430
JAN	23,765	23,455	8,782	14,217
FEB	22,076	21,977	21,250	14,321
MAR	21,702	17,334	16,300	10,779
APR	12,396	9,700		5,190

FUEL OIL USAGE (GAL/MSF)

	70-71	71-72	72-73	73-74
MAY	13.15	13.15	11.95	20.62
JUNE	2.20	2.55	3.44	2.22
JULY	1.11	1.01	7.14	1.97
AUG	1.28	1.01	0.92	1.56
SEPT	2.01	1.95	2.22	1.41
OCT	19.27	10.55	29.92	16.15
NOV	58.86	51.78	48.30	31.99
DEC		58.37	73.97	33.44
JAN	84.27	83.17	31.14	50.41
FEB	78.28	77.93	75.35	50.78
MAR	76.96	61.47	47.80	38.22
APR	43.96	34.40		18.43

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	96,000	108,000	128,400	126,000
AUG	92,400	120,000	124,800	109,200
SEPT	128,400	136,800	153,600	146,400
OCT	141,600	159,600	192,000	177,600
NOV	158,400		176,400	153,600
DEC	162,000	354,000	177,600	118,800
JAN	150,000	181,200	190,800	124,800
FEB	147,600	176,400	162,000	120,000
MAR	183,600	188,400		134,400
APR	142,800	162,000	322,800	127,680
MAY	174,000	205,200	182,400	
JUNE	138,000	178,800	163,200	

ELECTRICITY USAGE (KWH/MSF)

	70-71	71-72	72-73	73-74
JULY	340	383	455	447
AUG	328	426	443	387
SEPT	455	485	545	519
OCT	502	566	681	630
NOV	562		626	545
DEC	574	1255	630	421
JAN	532	643	677	443
FEB	523	626	578	426
MAR	651	667		477
APR	506	574	1145	453
MAY	617	728	647	
JUNE	489	634	579	

ELECTRICITY DEMAND

	70-71	71-72	72-73	73-74
JULY	312	408	372	372
AUG	312	408	384	420
SEPT	528	576	576	576
OCT	564	588	576	588
NOV	552		588	576
DEC	564	188	600	516
JAN	540	588	588	480
FEB	576	588	600	252
MAR	588	588		300
APR	552	576	1200	300
MAY	564	588	588	
JUNE	552	588	552	

FIGURE f-3/35:
SCHOOL NO. 12

f-3/51
Fuel and
Electricity Use

SCHOOL NO. 13: Intermediate School, Brooklyn
Year of Completion: 1963

BUILDING DESCRIPTION

Size: 188 msf
Floor to Floor Height: 10'-6"
Type of Construction: reinf. conc.
Skin: 4" brick, 2" air, 6" block
No. of Levels: 3
Ratio: Window Area to Skin Area of Typical Classroom Elevation: 52%
Ratio: Window Area to Typical Classroom Area: 37%
Ceiling Height of Typical Classroom: 10'-0"
Roof Insulation:

BOILER PLANT

No. of Boilers: 4
Burner Capacity:
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

Type: open window
Type of Exhaust System: central fan
Cfm/Typical Classroom: 560
Air-Conditioning: none

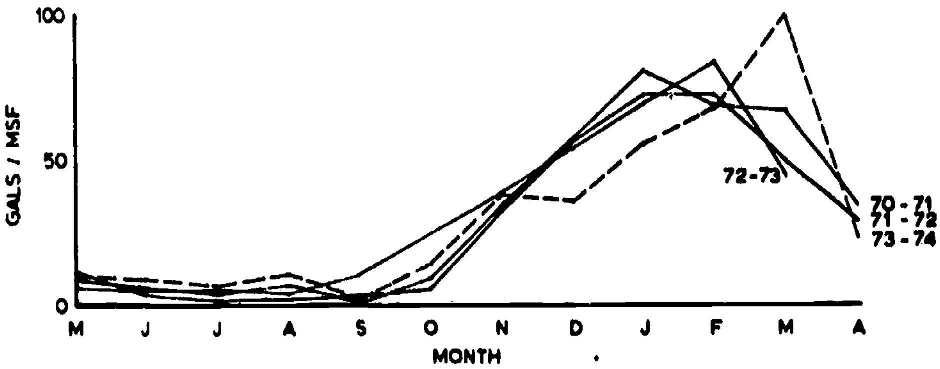
	Gymnasium	Auditorium
CFM:	14,750	14,850
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	manual	manual

ELECTRICAL

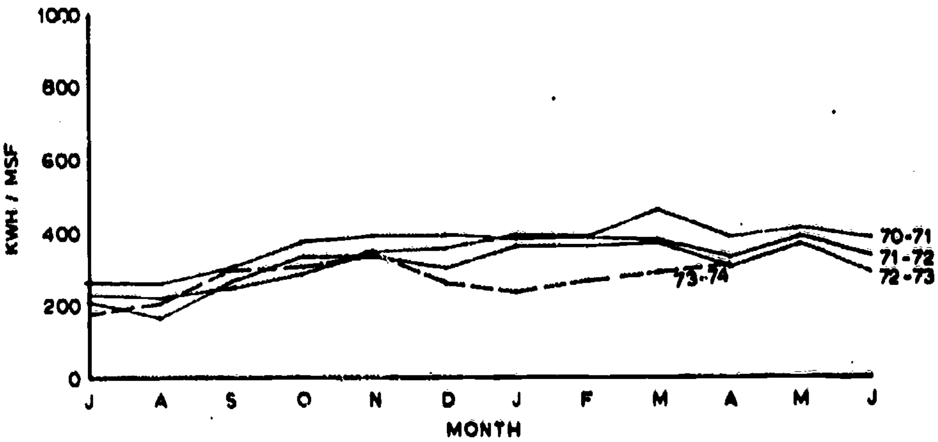
Watts/sf Typical Classroom: 2.4 Fixtures: fluorescent
Watts/sf Corridor: 1 Fixtures: fluorescent
Total Fan H.P.: 41
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen:

FIGURE f-3/36:
SCHOOL NO. 13

f-3/52
Fuel and
Electricity Use



FUEL OIL USAGE



ELECTRICITY USAGE

FIGURE f-3/37:
SCHOOL NO. 13

SCHOOL No. 13: INTERMEDIATE SCHOOL, BROOKLYN

SIZE: 188 MSF
YEAR OF COMPLETION: 1963

RGS & A-74

SCHOOL NO. 13: INTERMEDIATE SCHOOL
BROOKLYN

SIZE: 188 MSF
YEAR OF COMPLETION: 1963

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY	1,602	2,081	1,100	1,550
JUNE	1,212	700	1,050	1,550
JULY	700	300	1,010	1,100
AUG	1,450	400	620	2,050
SEPT	250	700	2,050	400
OCT	1,804	1,023		2,800
NOV	6,572	8,435	7,173	7,464
DEC		10,673	10,094	6,636
JAN	15,252	13,700	13,100	10,400
FEB	12,985	13,719	15,669	12,904
MAR	12,638	11,128	8,601	18,629
APR	6,545	5,270		4,530

FUEL OIL USAGE (GAL/MSF)

	70-71	71-72	72-73	73-74
MAY	8.52	11.07	5.85	10.37
JUNE	6.45	3.72	5.59	8.24
JULY	3.72	1.60	5.37	5.85
AUG	7.71	2.31	3.30	10.90
SEPT	1.33	3.72	10.90	2.13
OCT	9.60	5.44		14.89
NOV	34.96	44.87	38.15	39.70
DEC		56.77	53.69	35.29
JAN	81.13	72.87	69.68	55.32
FEB	69.07	72.97	83.35	68.64
MAR	67.22	59.19	45.75	99.09
APR	34.81	28.03		24.10

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	43,200	48,600	39,000	33,000
AUG	42,000	48,000	30,600	37,800
SEPT	46,800	56,400	46,600	55,200
OCT	52,800	70,200	61,800	55,800
NOV	64,800	73,200	61,800	63,000
DEC	67,200	73,800	55,800	48,000
JAN	73,800	72,000	67,800	45,000
FEB	72,600	72,600	67,800	58,600
MAR	85,800	71,400	70,200	54,000
APR	72,600	61,800	56,400	57,000
MAY	76,800	72,600	68,400	
JUNE	71,400	61,800	54,600	

ELECTRICITY USAGE (KWH/MSF)

	70-71	71-72	72-73	73-74
JULY	230	259	207	176
AUG	223	255	163	201
SEPT	249	300	259	294
OCT	281	373	329	297
NOV	345	389	329	335
DEC	357	393	297	255
JAN	393	383	361	239
FEB	386	386	361	258
MAR	456	380	373	287
APR	386	329	300	303
MAY	409	386	364	
JUNE	380	329	290	

ELECTRICITY DEMAND

	70-71	71-72	72-73	73-74
JULY	162	126	204	210
AUG	156	150	114	120
SEPT	234	264	258	204
OCT	246	264	282	276
NOV	270	276	282	282
DEC	282	276	276	282
JAN	282	288	276	252
FEB	276	288	276	252
MAR	282	282	270	516
APR	270	282	276	270
MAY	270	264	270	
JUNE	264	270	264	

FIGURE f-3/38:
SCHOOL NO. 13

SCHOOL NO. 14: Higher School, Manhattan
Year of Completion: 1958

BUILDING DESCRIPTION

Size: 251 msf
Floor to Floor Height: 12'-0"
Type of Construction: steel, conc. floor slab
Skin: 4" glass block
No. of Levels: 7
Ratio: Window Area to Skin Area of Typical
Classroom Elevation: 25%
Ratio: Window Area to Typical Classroom Area: 12%
Ceiling Height of Typical Classroom: 11'6"
Roof Insulation: 2"

BOILER PLANT

No. of Boilers: 3
Burner Capacity: 100 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

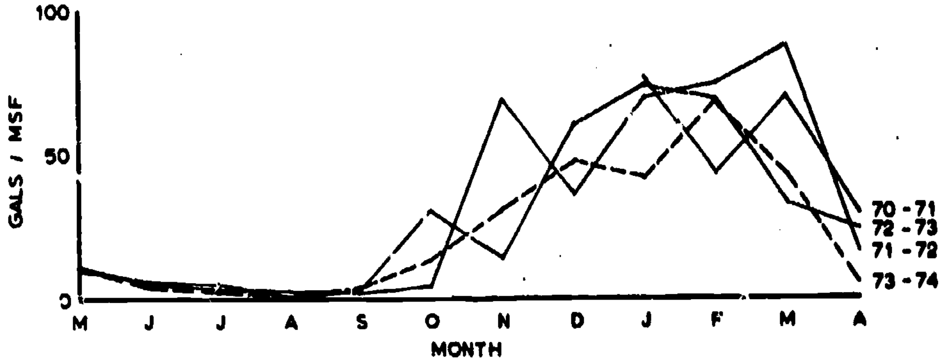
Type: open window
Type of Exhaust System: central fan
Cfm/Typical Classroom: 600
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	14,000	15,800
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	manual	manual

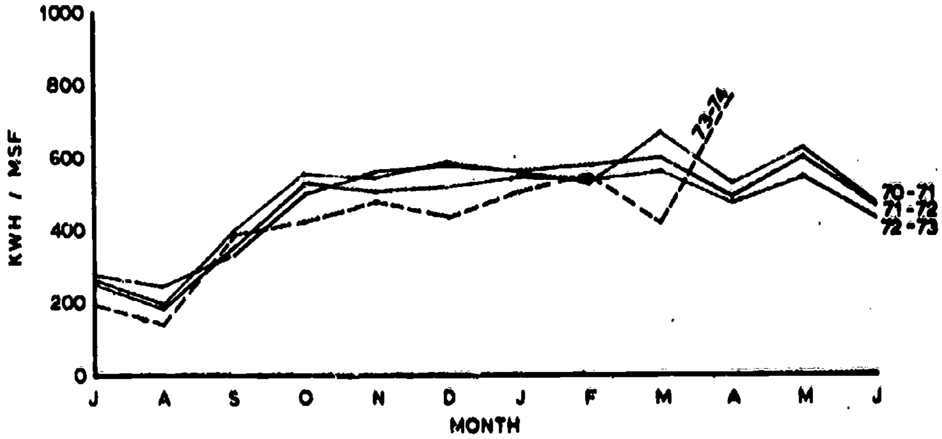
ELECTRICAL

Watts/sf Typical Classroom: 2.4 Fixtures: fluorescent
Watts/sf Corridor: 0.8 Fixtures: incandescent
Total Fan H.P.: 45
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen:

FIGURE f-3/39:
SCHOOL NO. 14



FUEL OIL USAGE



ELECTRICITY USAGE

SCHOOL No. 14: HIGH SCHOOL, MANHATTAN

SIZE: 251 MSF
YEAR OF COMPLETION: 1958

RGS&A-74

FIGURE f-3/40:
SCHOOL NO. 14

SCHOOL NO. 14: HIGH SCHOOL
MANHATTAN

SIZE: 251 MSF
YEAR OF COMPLETION: 1958

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY	2,050	2,980	2,756	2,858
JUNE	800	1,428	1,533	955
JULY		910	1,278	627
AUG		623	55	65
SEPT		544	749	956
OCT		1,137	7,552	3,273
NOV		17,256	3,618	7,696
DEC		9,032	15,040	11,897
JAN	19,142	17,346	18,392	10,391
FEB	10,715	18,621	16,935	16,846
MAR	17,467	21,880	8,222	10,809
APR	7,465	4,115	6,062	1,257

FUEL OIL USAGE (GAL/MSF)

	70-71	71-72	72-73	73-74
MAY	8.17	11.87	10.98	11.39
JUNE	3.19	5.69	6.11	3.80
JULY		3.63	5.09	2.50
AUG		2.48	0.22	0.26
SEPT		2.17	2.98	3.80
OCT		4.53	30.09	13.04
NOV		68.75	14.41	30.66
DEC		35.98	59.92	47.40
JAN	76.29	69.11	73.27	41.40
FEB	42.69	74.19	67.47	67.11
MAR	69.59	87.17	32.76	43.06
APR	29.74	16.39	24.15	5.01

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	64,800	69,600	62,400	48,000
AUG	49,200	61,200	45,600	34,000
SEPT	99,600	81,600	90,000	97,200
OCT	138,000	123,600	130,800	104,000
NOV	135,600	140,400	126,000	118,800
DEC	146,400	144,000	129,600	108,000
JAN	139,200	140,400	135,600	126,000
FEB	130,800	144,000	132,000	134,000
MAR	166,800	148,800	138,000	103,200
APR	130,800	121,200	118,800	190,800
MAY	154,800	148,800	134,400	
JUNE	117,600	116,400	105,600	

ELECTRICITY USAGE (KWH/MSF)

	70-71	71-72	72-73	73-74
JULY	258	277	249	191
AUG	196	244	182	135
SEPT	397	328	359	387
OCT	550	492	521	414
NOV	540	559	502	473
DEC	583	574	516	430
JAN	555	559	540	502
FEB	521	574	526	534
MAR	665	593	550	411
APR	521	483	473	760
MAY	617	593	534	
JUNE	469	454	421	

ELECTRICITY DEMAND

	70-71	71-72	72-73	73-74
JULY	252	300	300	
AUG	180	228	192	
SEPT	452	444	456	420
OCT	504	468	456	456
NOV	528	480	504	468
DEC	528	504	480	458
JAN	516	480	492	408
FEB	372	492	480	408
MAR	636	528	492	116
APR	504	492	480	372
MAY	504	492	456	
JUNE	492	468	420	

FIGURE f-3/41:
SCHOOL NO. 14

f-3/59
Fuel and
Electricity Use

SCHOOL NO. 15: High School, Bronx
Year of Completion: 1959

BUILDING DESCRIPTION

Size: 288 msf
Floor to Floor Height: 11'-8 5/8"
Type of Construction: reinf. conc.
Skin: 10"-12" masonry, no air space
No. of Levels: 4
Ratio: Window Area to Skin Area of Typical Classroom Elevation: 52%
Ratio: Window Area to Typical Classroom Area: 25%
Ceiling Height of Typical Classroom: 11'-0"
Roof Insulation: 2"

BOILER PLANT

No. of Boilers: 4
Burner Capacity: 55 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

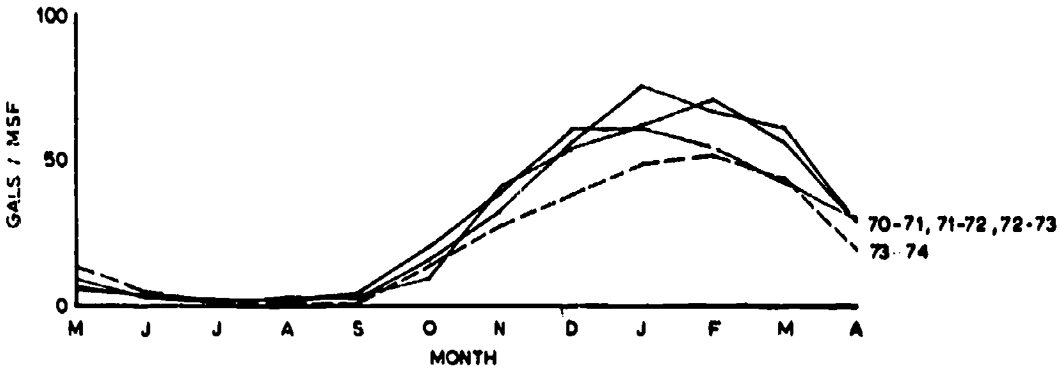
Type: open window
Type of Exhaust System: central fan
Cfm/Typical Classroom: 560
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	40,300	30,000
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	manual	manual

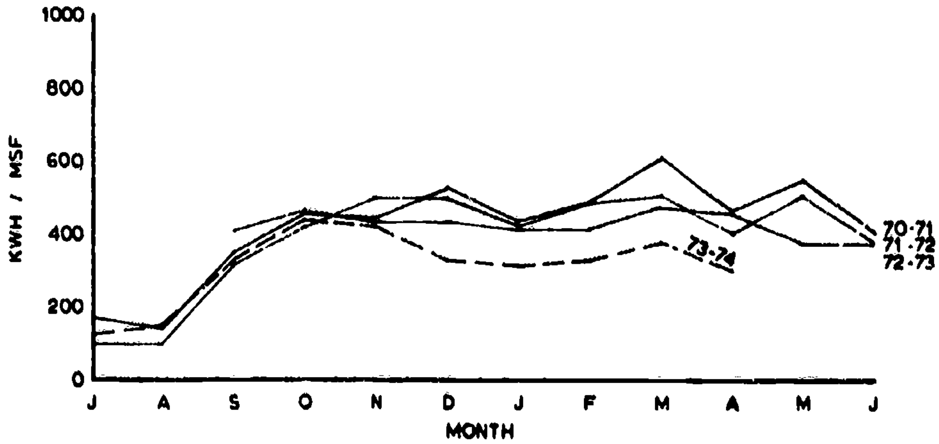
ELECTRICAL

Watts/sf Typical Classroom: 2.4 Fixtures: fluorescent
Watts/sf Corridor: 1 Fixtures: incandescent
Total Fan H.P.: 120
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen: yes

FIGURE f-3/42:
SCHOOL NO. 15



FUEL OIL USAGE



ELECTRICITY USAGE

FIGURE f-3/43:
SCHOOL NO. 15

SCHOOL No. 15: HIGH SCHOOL, BRONX

SIZE: 288 MSF
YEAR OF COMPLETION: 1959

RGS & A-74

SCHOOL NO. 15: HIGH SCHOOL
BRONX

SIZE: 288 MSF
YEAR OF COMPLETION: 1958-59

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY	2,578	1,820	1,500	3,757
JUNE	750	900	900	1,200
JULY	300	500	457	200
AUG	700	500	600	400
SEPT	700	800	900	300
OCT	4,707	2,746	6,000	3,927
NOV	9,288	11,825	11,150	7,789
DEC	16,208	15,320	17,530	10,899
JAN	21,632	17,855	17,650	13,847
FEB	19,436	20,340	15,566	14,681
MAR	17,754	16,109	12,214	12,220
APR	8,417	8,417	8,462	5,459

FUEL OIL USAGE (GAL/MSF)

	70-71	71-72	72-73	73-74
MAY	9.95	6.32	5.21	13.04
JUNE	2.60	3.13	3.13	4.17
JULY	1.04	1.74	1.59	0.69
AUG	2.43	1.74	2.08	1.39
SEPT	2.43	2.78	3.13	1.04
OCT	16.34	9.53	20.83	13.63
NOV	32.25	41.06	38.72	27.04
DEC	56.28	53.19	60.87	37.84
JAN	75.11	62.00	61.28	48.08
FEB	67.49	70.63	54.05	50.97
MAR	61.65	55.93	42.41	42.43
APR	29.23	29.23	29.38	18.95

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	48,000	27,600	40,800	34,800
AUG	39,600	27,600		40,800
SEPT	99,600	91,200	116,400	92,400
OCT	130,800	118,800	132,000	126,000
NOV	127,200	142,800	124,800	120,000
DEC	150,000	141,600	124,800	92,400
JAN	126,000	122,400	117,600	88,800
FEB	139,200	139,200	117,600	93,600
MAR	175,200	146,400	135,600	109,200
APR	133,200	115,200	132,000	85,200
MAY	157,200	144,000	108,000	
JUNE	115,200	109,200	108,000	

ELECTRICITY USAGE (KWH/MSF)

	70-71	71-72	72-73	73-74
JULY	167	96	142	121
AUG	138	96		142
SEPT	346	317	404	321
OCT	454	413	458	437
NOV	442	496	433	417
DEC	521	492	433	321
JAN	438	425	408	308
FEB	483	483	408	325
MAR	608	508	471	379
APR	463	400	458	295
MAY	546	500	375	
JUNE	400	379	375	

ELECTRICITY DEMAND

	70-71	71-72	72-73	73-74
JULY	180	168	372	108
AUG	192	144		120
SEPT	636	612	744	576
OCT	588	624	600	588
NOV	612	624	588	564
DEC	612	612	600	540
JAN	600	588	600	504
FEB	636	600	612	540
MAR	612	612	612	516
APR	636	612	600	540
MAY	612	600	720	
JUNE	588	588	588	

FIGURE f-3/44:
SCHOOL NO. 15

f-3/63
Fuel and
Electricity Use

SCHOOL NO. 16: Intermediate School, Brooklyn
Year of Completion: 1968

BUILDING DESCRIPTION

Size: 164 msf
Floor to Floor Height: 10'-8"
Type of Construction: reinf. conc./waffle slabs
Skin: 4" brick, 2" air, 4" block
No. of Levels: 4
Ratio: Window Area to Skin Area of Typical Classroom Elevation: 5%
Ratio: Window Area to Typical Classroom Area: 2%
Ceiling Height of Typical Classroom: 10'-4"
Roof Insulation:

BOILER PLANT

No. of Boilers: 3
Burner Capacity: 58.8 gal/hr
Type of Boiler: fire box
Heating System: steam radiation/vacuum return
Type of D.H.W. Generation: heat exchanger

VENTILATION SYSTEM

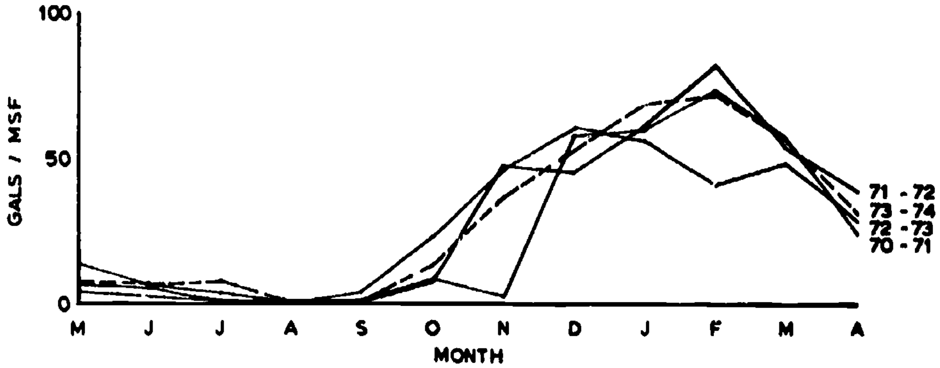
Type: cabinet
Type of Exhaust System: central fan
Cfm/Typical Classroom: 560
Air Conditioning: none

	Gymnasium	Auditorium
CFM:	12,300	13,100
% Outside Air:	100	100
Recirculation:	yes	no
Controls:	auto	-

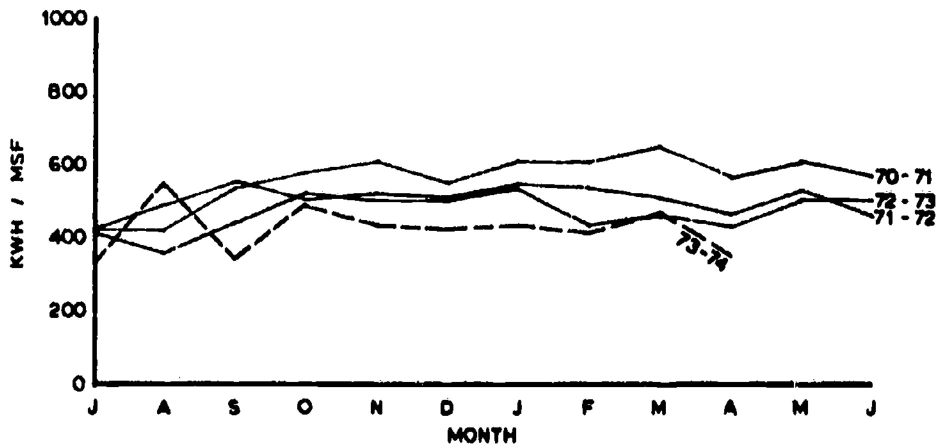
ELECTRICAL

Watts/sf Typical Classroom: 2.7 Fixtures: fluorescent
Watts/sf Corridor: 2 Fixtures: fluorescent
Total Fan H.P.: 63
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen: yes

FIGURE f-3/45:
SCHOOL NO. 16



FUEL OIL USAGE



ELECTRICITY USAGE

FIGURE f-3/46:
SCHOOL NO. 16

SCHOOL No. 16 : INTERMEDIATE SCHOOL, BROOKLYN

SIZE: 164 MSF
YEAR OF COMPLETION: 1968

RGS&A-74

SCHOOL NO. 16: INTERMEDIATE SCHOOL
BROOKLYN

SIZE: 164 MSF
YEAR OF COMPLETION: 1968

FUEL OIL USAGE (GAL TOTAL)

	70-71	71-72	72-73	73-74
MAY	735	1,234	3,000	1,280
JUNE	440	934	1,000	1,038
JULY	200	100	530	1,238
AUG		100	50	0
SEPT	200	200	588	200
OCT	1,350	1,250	3,900	2,200
NOV	4,300	7,800	7,654	5,919
DEC	9,500	7,525	9,891	8,528
JAN	9,900	9,910	9,194	11,400
FEB	12,112	13,550	6,738	11,821
MAR	9,500	9,000	7,876	9,464
APR	[illegible]	6,500	4,600	5,190

FUEL OIL USAGE (GAL/MSF)

	70-71	71-72	72-73	73-74
MAY	4.48	7.52	18.29	7.80
JUNE	2.68	5.70	6.10	6.33
JULY	1.22	0.61	3.23	7.55
AUG		0.61	0.30	0
SEPT	1.22	1.22	3.59	1.22
OCT	8.23	7.62	23.78	13.41
NOV	2.62	47.56	46.67	36.09
DEC	57.93	45.88	60.31	52.00
JAN	60.37	60.43	56.06	69.51
FEB	73.85	82.62	41.09	72.08
MAR	57.93	54.88	48.02	57.71
APR	24.39	39.63	28.05	31.65

ELECTRICITY USAGE (KWH TOTAL)

	70-71	71-72	72-73	73-74
JULY	69,600	69,600	66,000	55,200
AUG	68,400	80,400	58,800	89,800
SEPT	87,600	90,000	72,000	55,200
OCT	94,800	81,600	85,200	79,200
NOV	99,600	85,200	81,600	70,800
DEC		94,000	81,600	69,600
JAN	189,600	90,000	87,600	70,800
FEB	99,600	87,600	70,800	67,200
MAR	108,000	84,000	75,600	78,000
APR	92,400	75,600	70,800	57,600
MAY	100,800	86,400	82,800	
JUNE	92,400	75,600	82,800	

ELECTRICITY USAGE (KWH/MSF)

	70-71	71-72	72-73	73-74
JULY	424	424	402	337
AUG	417	490	359	548
SEPT	534	549	439	337
OCT	578	498	520	483
NOV	607	520	498	432
DEC		512	498	424
JAN	1156	549	534	432
FEB	607	534	432	410
MAR	659	512	461	476
APR	563	461	432	351
MAY	615	527	505	
JUNE	563	461	505	

ELECTRICITY DEMAND

	70-71	71-72	72-73	73-74
JULY	204	180	192	168
AUG	156	204	156	242
SEPT	312	288	264	288
OCT	336	276	288	276
NOV	312	288	300	408
DEC		276	288	312
JAN	672	264	276	288
FEB	348	276	264	
MAR	312	240	288	288
APR	312	240	264	180
MAY	312	240	264	
JUNE	300	216	240	

FIGURE f-3/47:
SCHOOL NO. 16

f-3/67
Fuel and
Electricity Use

For the purposes of comparison with New York City Schools the energy uses of five suburban schools have been recorded on the following page. Fuel and electricity consumption figures reflect economy measures instituted December 1, 1973, and maintained for a ten-month period.

SURBURBAN SCHOOL NO. 1

Year of Completion: 1957

BUILDING DESCRIPTION

Size: 350 msf
Floor to Floor Height: 10' 9"
Type of Construction: steel frame
Skin: panel (1" insulation)
No. of Levels: 2
Ratio: Window Area to Skin Area of Typical Classroom Elevation: 50%
Ratio: Window Area to Typical Classroom Area: 22%
Ceiling Height of Typical Classroom: 9' 0"
Roof Insulation: 4" insul. roof deck

BOILER PLANT

No. of Boilers: 5
Burner Capacity: 200 gal/hr
Type of Boiler: fire box
Heating System: steam, vacuum return
Type of D.H.W. Generation: steam

VENTILATION SYSTEM

Type: unit ventilators
Type of Exhaust System: stack
Cfm/Typical Classrm: 750 Area/Typical Classrm: 720 sf
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	67,200	31,700
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	auto	auto

ELECTRICAL

Watts/sf Typical Classrm: 2
Watts/sf Corridor: 1.5
Total Fan H.P: 80
Total Pump H.P.:10
Total Refrigeration H.P: none
Electric Kitchen: no

FUEL & ELECTRICITY USAGE

	kwh	kwh/msf	Gals #6 Fuel Oil	Gals/msf
71-72			330,000	940
72-73	2,400,000	6,800	385,000	1,100
73-74	2,000,000	5,700	286,000	817

FIGURE f-3/48:
SUBURBAN
SCHOOL NO. 1

Note: 10-month economy measures instituted December 1, 1973 for 5 suburban schools.

f-3/69
Fuel and
Electricity Use

SUBURBAN SCHOOL NO. 2
Year of Completion: 1965

BUILDING DESCRIPTION

Size: 86 msf
Floor to Floor Height: 11' 4"
Type of Construction: concrete
Skin: 8" concrete, 2" air, 4" brick
No. of Levels: 2
Ratio: Window Area to Skin Area of Typical
Classroom Elevation: 60%
Ratio: Window Area to Typical Classroom Area: 18%
Ceiling Height of Typical Classroom: 9' 0"
Roof Insulation: 3" insulated roof deck

BOILER PLANT

No. of Boilers: 2
Burner Capacity: 30 gal/hr
Type of Boiler: fire box
Heating System: hot water
Type of D.H.W. Generation: from boiler

VENTILATION SYSTEM

Type: unit ventilators
Type of Exhaust System: stack
Cfm/Typical Classroom: 1250 Area/Typical Classrm: 900 sf
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	6,000 (unit vent.)	8,000
% Outside Air:		100
Recirculation:		yes
Controls:		oil

ELECTRICAL

Watts/sf Typical Classroom: 1.5
Watts/sf Corridor: 1.0
Total Fan H.P.: 9
Total Pump H.P.: 10.5
Total Refrigeration H.P: none
Electric Kitchen: partial

FIGURE f-3/49: SUBURBAN SCHOOL NO. 2

FUEL & ELECTRICITY USAGE

	kwh	kwh/msf	Gals #4 Fuel Oil	Gals/msf
71-72			62,600	727
72-73	320,000	3,720	62,200	723
73-74	309,000	3,600	36,700	427

SUBURBAN SCHOOL NO. 3
Year of Completion: 1949

BUILDING DESCRIPTION

Size: 59 msf
Floor to Floor Height: 10' 0"
Type of Construction: reinforced concrete
Skin: 8" block, 2" air, 4" brick
No. of Levels: 2
Ratio: Window Area to Skin Area of Typical
Classroom Elevation: 50%
Ratio: Window Area to Typical Classroom Area: 24%
Ceiling Height of Typical Classroom: 8' 3"
Roof Insulation: 1"

BOILER PLANT

No. of Boilers: 2
Burner Capacity: 90 gal/hr
Type of Boiler: fire box
Heating System: steam
Type of D.H.W. Generation: steam

VENTILATION SYSTEM

Type: unit ventilators
Type of Exhaust System: stack
Cfm/Typical Classrm: 1,000 cfm Area/Typical Classrm: 960 sf
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	890	3,600
% Outside Air:	100	100
Recirculation:	yes	yes
Controls	auto	auto

ELECTRICAL

Watts/sf Typical Classrm: 1.67 Fixtures: fluorescent
Watts/sf Corridor: 1.23 Fixtures: fluorescent
Total Fan H.P.: negligible
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen: no

FUEL & ELECTRICITY USAGE

	kwh	kwh/msf	Gals #4 Fuel Oil	Gals/msf
71-72			45,500	771
72-73	205,000	3,475	56,000	949
73-74	208,000	3,534	32,700	554

FIGURE f-3/50:
SUBURBAN
SCHOOL NO. 3

f-3/71
Fuel and
Electricity Use

SUBURBAN SCHOOL NO. 4
Year of Completion: 1952

BUILDING DESCRIPTION

Size: 200 msf
Floor to Floor Height: 13' 1"
Type of Construction: concrete
Skin: 4" brick, 8" concrete
No. of Levels: 2
Ratio: Window Area to Skin Area of Typical Classroom Elevation: 50%
Ratio: Window Area to Typical Classroom Area: 25%
Ceiling Height of Typical Classroom: 11' 6"
Roof Insulation: 2" rigid insulation over 12" concrete slab

BOILER PLANT

No. of Boilers: 3
Burner Capacity: 100 gal/hr
Type of Boiler: fire box
Heating System: steam
Type of D.H.W. Generation: steam

VENTILATION SYSTEM

Type: unit ventilator
Type of Exhaust System: combination central fan and stack
Cfm/Typical Classrm: 500 Area/Typical Classrm: 690 sf
Air-Conditioning: none

	Gymnasium	Auditorium
CFM:	20,278	23,650
% Outside Air:	100	100
Recirculation:	yes	yes
Controls:	auto	auto

ELECTRICAL

Watts/sf Typical Classroom: 2.0 Fixtures: fluorescent
Watts/sf Corridor: 1.5 Fixtures: incandescent
Total Fan H.P.: 37
Total Pump H.P.: negligible
Total Refrigeration H.P.: none
Electric Kitchen: ½ gas

FUEL & ELECTRICITY USAGE

	kwh	kwh/msf	Gals #6 Fuel Oil	Gals/msf
71-72			134,500	700
72-73	931,000	4,850	146,500	760
73-74	750,000	3,900	103,000	536

FIGURE f-3/51:
SUBURBAN
SCHOOL NO. 4

f-3/72
Fuel and
Electricity Use

SURBURBAN SCHOOL NO. 5

BUILDING DESCRIPTION

Size: 26 msf
Floor to Floor Height: 12' 8"
Skin: 2' 8" brick, ½" insulation
No. of Levels: 1
Ratio: Window Area to Skin Area of Typical
Classroom Area: 65%
Ratio: Window Area to Typical Classroom Area: 30%
Ceiling Height of Typical Classroom: 11' 0"
Roof Insulation: 1" insulation over concrete slab

BOILER PLANT

No. of Boiler: 2
Burner Capacity: 18 gal/hr
Type of Boiler: hot water
Heating System: hot water with hot air
Type of D.H.W. Generation: immersed coil from boiler

VENTILATION SYSTEM

Type: central supply
Type of Exhaust System: stack
Cfm/Typical Classrm: 400 Area/Typical Classrm: 1064 sf
Air-Conditioning: none

	Gymnasium
CFM:	2,400
% Outside Air:	100
Recirculation:	yes
Controls	auto

ELECTRICAL

Watts/sf Typical Classrm: 2.0 Fixtures: fluorescent
Watts/sf Corridor: 1.42 Fixtures: incandescent
Total Fan H.P.: 2.75
Total Pump H.P.: 3.5
Total Refrigeration H.P.: none
Electric Kitchen: none

FUEL & ELECTRICITY USAGE

		kwh	kwh/msf	Gals #4 Fuel Oil	Gals/msf
FIGURE f-3/52:	71-72			33,100	1,273
SUBURBAN	72-73	100,560	3,868	33,000	1,270
SCHOOL NO. 5	73-74	65,400	2,515	25,000	960

f-4

fuel and electricity use in nyc schools

4 ● DETAILED SYSTEM ANALYSIS OF SELECTED SAMPLE

A recently constructed intermediate school was evaluated in terms of energy flow (in and out) and energy consuming systems. The purpose of the following study is to approximate the proportions of energy consumed by various major systems of school buildings.

Calculated Fuel Oil Usage

The data below shows the design calculated heat losses for typical spaces in a recently constructed New York City school. Of major interest is the percentage of heat loss resulting from introduction of outside air (between 64 percent and 79 percent).

<u>Typical Classroom</u>:
Transmission Heat Loss = 19,700 btuh (34 percent)
Ventilation Heat Loss = 37,900 btuh (66 percent)
Grand Total Heat Loss = 57,600 btuh

<u>Auditorium</u>:
Transmission Heat Loss = 177,000 btuh (22 percent)
Ventilation Heat Loss = 645,000 btuh (78 percent)
Grand Total Heat Loss = 822,000 btuh

<u>Gymnasium</u>:
Transmission Heat Loss = 192,850 btuh (21 percent)
Ventilation Heat Loss = 705,000 btuh (79 percent)
Grand Total Heat Loss = 897,850 btuh

Calculated Electricity Usage

The same recent New York City school on which the preceeding heat loss calculations were made was evaluated for anticipated electricity usage. The results are shown below:

Scheme A: Design Conditions

<u>(Limited and Conservative Utilization</u>)
180 days per school year, ventilation nine months, heating six months, cooling three months. (No afternoon, evening or summer session included).

Lighting Usage: Classrooms 6 hrs/day; corridor and stairs 8

hrs; offices 7 hrs; auditiorium 2 hrs; stage ½ hr; gymnasium 4 hrs; unfinished spaces 4 hrs; shops and labs 5 hrs.

Scheme B: Design Conditions

(Less Conservative Utilization)
180 days per school year, ventilation nine months, heating and cooling same as Scheme A for monthly use, but increased for daily use. Classroom 7 hrs/day; corridor and stairs 9 hrs; offices 8 hrs; auditorium 3 hrs; stage ½ hr; gymnasium 5 hrs; unfinished spaces 4 hrs; shops and labs 6 hrs.

Scheme A: Electricity Usage

(Limited and Conservative Utilization)

	wh/sf/day	kwh/sf/yr
Lighting	9.66	1.74
Ventilating	3.68	.66
Heating	.79	.10 (6 months)
Cooling		
Absorption		
Auxiliaries		
Electric Drive	4.10	.25 (3 months partial sf)
Miscellaneous		
Heat up Kitchen		
Labs and Shops	1.60	.29
Rec. Loads		
Totals	19.83	3.04

Scheme B: Electricity Usage

(Less Conservative Utilization)

	wh/sf/day	kwh/sf/yr
Lighting	11.20	2.01
Ventilating	4.21	.75
Heating	.92	.11
Cooling	4.36	.26
Absorption		
Auxiliaries		
Electric Drive		
Miscellaneous	1.76	.31
Heat up Kitchen		
Labs and Shops		
Rec. Loads		
Totals	22.45	3.44

Scheme A:
Heating
Ventilating
Air-Conditioning

(Back up Information for 190 msf Building: 122 msf Cooled by Absorption)

	kwh/day	wh/sf/day	kwh/sf/yr
Ventilation	700	3.68	.66
Heating	150	.79	.10
Cooling	780	4.10	.25
Misc.	305	1.60	.29

Scheme A:
Lighting

	sf	total w	hrs/day	kwh/day	wh/sf/day
Classrooms	77,887	155,204	6	930	11.94
Corridor & Stairs	30,353	30,000	8	240	7.91
Offices	10,172	22,448	7	157	15.43
Auditorium					
House	6,084	34,936	2	69	11.34
Stage	1,080	14,800	½	7	6.48
Shops	4,702	10,212	5	51	6.48
Labs	8,056	16,284	5	81.1	10.06
Gymnasium	11,760	25,576	4	102	8.67
Unfinished	39,906	38,180	4	152	3.28
Additional Night Light	-	12,000	4	48	1.58
Total	190,000	359,640		1,837	9.66

Watts/sf = 1.89
Wh/sf/day = 9.66 @ 180 days = 1.74 kwh/sf/school year

Scheme B:
Heating
Ventilating
Air-Conditioning

	kwh/day	wh/sf/day	kwh/sf/yr
Ventilation (9 mos)	800	4.21	.75
Heating (6 mos)	175	.92	.11
Cooling (3 mos)	830	4.36	.26
Misc.	305	1.60	.29

f-4/3

Scheme B:
Lighting

	sf	total w	hrs/day	kwh/day	wh/sf/day
Classrooms	77,887	155,204	7	1,086	13.94
Corridor & Stairs	30,353	30,000	9	270	8.89
Auditorium					
House	6,084	34,936	3	105	17.25
Stage	1,080	14,800	½	7	6.48
Shops	4,702	10,212	6	61.3	13.03
Labs	8,056	16,284	6	97.7	12.12
Gymnasium	11,760	25,576	5	128.	10.88
Unfinished	46,306	38,180	4	153	3.30
Additional					
Night Light	-	12,000	4	48	1.58
Offices	10,172	22,448	8	179	17.59
Total	190,000	359,640		2,128	11.20

Watts/sf = 1.89

Wh/sf/day =11.20 @ 180 days = 2.01 kwh/sf/school year

f-4/4

f-5

fuel and electricity use in nyc schools

5● PRELIMINARY ANALYSIS OF EMERGENCY ENERGY-SAVING MEASURES INITIATED BY THE NYC BOARD OF EDUCATION 1973 - 1974

In November, 1973 in response to the emergence of the fuel crisis, the New York City Board of Education instituted a program geared to reducing the already low energy use in its buildings. A series of circulars were sent to all school custodians outlining specific methods of conserving energy. Copies of relevant portions of these circulars are included in this section. The circular from December 3, 1973 is included in its entirety.

Monthly fuel oil and electricity usage was compared for the sixteen samples for December through April 73-74 with the average of the same five months for the three preceeding years. Fifteen of the sixteen showed lower fuel oil use with savings ranging from 7.6 percent to 39.9 percent. The one school showing an increase had a 7.3 percent rise. The average fuel use for the sixteen schools was 24.4 percent below the average for the three previous years. The 1973-74 winter was slightly warmer than the previous three years. The savings were adjusted accordingly resulting in a corrected figure of 19.1 percent. Fifteen of the sixteen schools showed a decrease in electricity usage with savings ranging from 4 percent to 37.3 percent. The one school showing an increase gained 8.4 percent in usage. This was not the same school which had shown an increase in fuel oil usage. The overall average of electrical usage was down by 20.0 percent.

The above results are of particular interest coming from the New York City system because they indicate that even within a highly efficient building plant, representing the state of the art of energy control, a re-evaluation of basic criteria can yield significant savings.

FIGURE f-5/1: COMPARISON OF ENERGY USAGE 1970-73 VERSUS 1973-74*

School	Aver. Fuel Use 70-73* gal/msf/mo	Aver. Fuel Use 73-74* gal/msf/mo	Percent Change	Aver. Elec. Use 70-73* kwh/msf/mo	Aver. Elec. Use 73-74* kwh/msf/mo	Percent Change
1	81.78	55.23	-32.5	772	648	-16.1
2	70.30	64.17	- 8.7	452	395	-12.6
3	76.85	51.05	-33.6	1228	770	-37.3
4	70.64	56.03	-20.7	553	492	-11.0
5	71.42	60.13	-15.8	434	415	- 4.4
6	69.80	44.99	-35.5	490	367	-25.1
7	66.71	47.48	-28.8	467	406	-13.1
8	63.31	45.62	-27.9	411	351	-14.6
9	62.61	46.29	-26.1	544	380	-30.1
10	66.53	40.34	-39.4	333	361	+ 8.4
11	60.26	47.63	-21.0	441	340	-22.9
12	63.62	38.26	-39.9	597	444	-25.6
13	61.12	56.49	- 7.6	369	268	-27.4
14	54.20	40.80	-24.7	549	527	- 4.0
15	53.92	39.65	-25.5	467	326	-30.2
16	52.76	56.59	+ 7.3	525	419	-20.2
	65.36	49.42	-24.4	540	432	-20.0

NOTE: For the 70-73 period, the five months evaluated averaged a total of 3905 degree days. For 73-74 the five months totalled 3651 degree days. This is a 6.5 percent reduction in heating load. When corrected for the degree day difference the saving in fuel oil use becomes 19.1 percent.

*Emergency Energy Saving Measures in Effect. Data for December, January, February, March, April.

BOARD OF EDUCATION OF THE CITY OF NEW YORK
DIVISION OF SCHOOL BUILDINGS
OFFICE OF PLANT OPERATION AND MAINTENANCE
BUREAU OF PLANT OPERATION

December 3, 1973

PLANT OPERATION CIRCULAR NO. 13 - 1973/74

NOTE: All Circulars are to be kept in a permanent file

TO SCHOOL CUSTODIAN ENGINEERS AND SCHOOL CUSTODIANS

1. FUEL AND ENERGY CRISIS

The fuel and energy crisis in the United States becomes more critical each week. So that all of us both at work and at home do not end up freezing in the dark we must take steps to conserve all types of fuel and energy, i.e. coal, oil, electricity, gas, gasoline, outside steam and hot water.

The Board of Education has directed that room temperatures be lowered still further so that the maximum temperature in any school building will be 68° F. The only exception to this will be natatoriums. In these areas ambient temperatures will be kept 3° above pool water temperature. Pool water temperatures will be maintained at 73-74° F. during the winter season.

The State Education Department has relaxed some of their requirements in reference to building operations for the duration of the crisis. These relaxations are:

1. Classroom or office temperatures are not to exceed 68° F.
2. Gymnasiums, shops, cafeterias, or any non-sedentary space should be heated to a range of 63 to 65°.
3. Lighting levels have been reduced to:
   10 foot candles - in auditoriums, corridors, locker rooms, toilets.
   20 foot candles - in cafeterias, gymnasiums.
   30 foot candles - classrooms, libraries, offices, shops.
   40 foot candles - rooms where fine detail work is done such as sewing rooms, drafting rooms.
4. Fresh air supply has been reduced to 4 cfm.

It is understood that meters and test gauges are not available to determine foot candles and air flow. However, "trial and error" should be employed to conserve fuel and energy. A modern classroom has lighting equipment to provide 50-70 foot candles. Switches for light strips next to windows may be taped in the off position to reduce light level. In some schools every other fixture in corridors may be shut off. Where incandescent lamps are installed wattage may be reduced. DO NOT, however, reduce illumination to point you have created a hazardous condition. Where fluorescent fixtures are involved care must be taken not to burn out ballasts. In cases where dual tube fixtures are involved either both tubes must be installed or removed. Use of dual tube fixtures with only one tube may burn out ballast.

Custodians must review work schedules in order to cut down total time lights are on. Is it possible to advance reporting times of night crews so that heat and lights may be reduced earlier? Checks must be made that teachers turn room lights off when they leave. Custodial workers can turn them back on when necessary for cleaning.

f-5/3

FUEL AND ENERGY CRISIS, Continued

Where possible water temperatures to slop sinks, lavatories, etc., should be reduced to a maximum of 100° F. This is possible where a booster heater is installed in line to cafeteria kitchen. Where a mixing valve is installed to reduce temperatures to washrooms, etc., it is suggested you request permission from Principal to shut off hot water to lavatories.

It will be necessary from all available information to reduce fuel consumption by at least 20% from 1972/73 consumption. Since last winter was reasonably warm this will be difficult to achieve. Your fuel and utility cards will be checked closely each month to insure your consumption has been reduced. If adequate savings are not achieved the next step will be to cancel afternoon and evening activities. Your full cooperation is requested and expected to achieve the required fuel and energy savings to keep our schools open.

The Board of Education has directed that the enclosed questionnaire on the fuel and energy crisis be completed by each Custodian. One copy must be returned to your Borough Supervisor of School Custodians by December 10, 1973.

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2. MEMBER OF PERSONNEL BOARD

The following have been elected to the Personnel Board for the period January 1974 to January 1977:

Mr. George Maggio - Division of School Buildings
Mr. Charles Hughes (Alternate) - Bureau of School Lunches

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3. OIL BURNER EMERGENCIES

Too many oil burner emergencies have turned out to be minor problems such as a tripped circuit breaker, a blown fuse, cold oil. The Custodian must check his plant out personally before requesting emergency oil burner service.

HUGH McLAREN JR.
Executive Director
Division of School Buildings

RGH:NS
Enclosure: Fuel and Energy Questionnaire (2)

BOARD OF EDUCATION OF THE CITY OF NEW YORK
DIVISION OF SCHOOL BUILDINGS
OFFICE OF PLANT OPERATION AND MAINTENANCE
BUREAU OF PLANT OPERATION

SCHOOL____________________ BOROUGH__________

FUEL AND ENERGY QUESTIONNAIRE

Where question indicates condition of equipment, any conditions that are creating fuel or energy losses should be reported on a P.O. 18 and submitted with this questionnaire.

1. Have all thermostats been set back to 68° F. or less? ________
2. Is all temperature control on hot water heating or ventilating systems in good operating condition? ________
3. Has schedule been set up for operation of indirect ventilating systems? ________
4. Are firesides of boilers cleaned regularly at every 100 hours of operation? ________
5. Is boiler water treated? What was last pH or OD reading? ________
6. Are there any leaks in water or steam side of boiler? ________
7. Are there excess air leaks in fireside of boiler? ________
8. (a) Are there any leaks in steam piping or valves? (a)________
   (b) Is there shop order or specification for repair? (b)________
9. (a) Are there any faulty steam traps? (a)________
   (b) Have you replacements parts? (b)________
   (c) Is there specification or shop order out for repair? (c)________
10. Have you set up schedule of closing header, riser or branch valves to isolate unoccupied parts of building? ________
11. Are fuel burning controls in good operation condition? (Oil, Coal, Gas, Electric) ________
12. (a) Have you taken a recent CO_2 test? (a)________
    (b) What was or is CO_2 percentage? (b)________
    (c) What was stack temperature at time of test? (c)________
13. Has plant a Department of Air Resources Operating Certificate?
    (a) Oil Burners (a)________
    (b) Incinerators (b)________
14. Has hot water tank been cleaned recently, give date of last cleaning? ________
15. If booster heater has been installed for cafeteria kitchen hot water has house supply been reduced to 100° F. ________
16. Are there any leaks in hot water piping valves or faucets? ________
17. Are fresh air intake dampers in working order? ________
18. Have fresh air intake dampers been adjusted to reduce fresh air intake to bare minimum (State Education has reduced requirement to 4 cfm/person for duration of energy crisis)? ________
19. Have all holdbacks, chains, etc., been removed from exterior doors? ________

f-5/5

FUEL AND ENERGY QUESTIONNAIRE

20. Are all door checks on exterior doors in good working order? ______________

21. Are all windows in good condition?
    (a) Is glass replaced or backed up? (a)__________
    (b) Do they close properly and stay closed overnight? (b)__________
    (c) Are they weather stripped? (c)__________
    (d) Do they need weather stripping? (d)__________

22. (a) Have you checked building operation for conservation of electricity? (a)__________
    (b) Can you reduce lighting in corridors? (b)__________
    (c) Can you reduce lighting in classrooms? (c)__________
    (d) Have you instructed your employees in conservation of electricity? (d)__________
    (e) Have teachers cooperated in conservation of electricity? (e)__________
    (f) Have teachers been made aware of fuel and energy crisis by Principal or School Board? (f)__________
    (g) Have "Save-A-Watt" stickers been put on light switches? (g)__________

23. Have you inspected cafeteria/lunchroom kitchens for possible fuel or energy wasters? ______________
    (a) Refrigerator/freezer doors, are they tight (a)__________
    (b) Refrigerating machine condensers, are they clean? (b)__________
    (c) Is refrigerant at proper level so that machines does not run continuously? (c)__________

24. (a) Are filters on ventilating equipment clean? (a)__________
    (b) When were they last checked? (b)__________

25. Do you have any unique ways to conserve either fuel or energy in your school? Do you have any ideas how fuel might be saved in your school or others by some simple or inexpensive change in scheduling, wiring, piping, etc? Please give details.

DATE____________________ SIGNATURE ______________________________
SCHOOL CUSTODIAN ENGINEER/SCHOOL CUSTODIAN

RETURN TO BOROUGH SUPERVISOR OF SCHOOL CUSTODIANS BY DECEMBER 10, 1973

f-5/6

From
Circular #7
19 October 1973

2. FUEL CONSERVATION

The fuel situation in New York City may become extremely critical durig the forthcoming winter. School Custodians/Engineers are directed to take every measure consistent with health and safety to conserve fuel. The following are some items that will help in the conservation of fuel:

a. Classroom and office temperatures are to be maintained at no higher than 70° F.
b. Indirect ventilating systems in areas such as gymnasiums and auditoriums are not to be operated when areas are not occupied.
c. Broken window glass must be replaced or backed up promptly.
d. Fire sides of boilers must be cleaned at every 100 hours of operation.
e. Combustion should be checked regularly for proper CO_2 percentage.
f. Leaks on steam and condensate lines must be repaired or reported for repair promptly.
g. Where possible header valves controlling steam to sections of the building not in use for activities should be shut.
h. Door checks on exterior doors should be kept in good operating condition.
i. An indirect fuel economy is conservation of electricity. Any fuel saved by Edison will make more fuel for heating available.
j. Fuel oil temperatures must be checked closely to provide for proper combustion. The quality of oil delivered may change during the winter. A close check on combustion should be kept after the delivery of each new load of oil.
k. In schools where two or more fuel tanks are installed, one tank should be kept in use until a full load of oil can be placed in tank. The average load of oil is 5500 gallons. This way tanks can be kept topped off whenever fuel is available. This will be most important this winter since we will want to take whatever oil the vendor can make available.

From
Circular #10
9 November 1973

1. FUEL CONSERVATION

The fuel situation is extremely critical. The procedures outline in Plant Operation Circular #7 - 1973/74 must be complied with. Any additional conservation procedures that you may be able to institute consistent with health and safety should be adopted.

From
Circular #15
16 January 1974

3. FUEL CONSERVATION

The results of your efforts in fuel conservation are gratifying. The goals set for conservation of fuel and utilities have been met. The crisis is still with us so please do not relax your efforts. It is not only important now to conserve fuel and energy because of the shortage but also because of the cost. Costs for both have skyrocketed.

From
Circular #21
17 April 1974

1. FUEL CONSERVATION

Although the fual crisis has abated the necessity to conserve fual continues. Fuel is not in abuntant supply. In addition to the short supply, conservation is necessary because of price. The price of oil has more than doubled in the past six months. This increase has created a serious shortage in budget allocations. Please continue the exemplary efforts you have exerted throughout the winter in conserving fuel.

From
Circular #24
29 May 1974

5. USE OF AIR CONDITIONING EQUIPMENT

In those schools and offices where air conditioning equipment is installed the following rules should be followed to conserve energy.

a. Air conditioning equipment should not be operated until room temperature reaches 78° F.
b. Thermostat settings must not be less than 78° F.
c. Occupants should be instructed in the use of shades and blinds to reduce solar heat load.
d. Occupancy of large air conditioned areas by a single person should be avoided where possible. Request occupants to consolidate use of air conditioned space.
e. Instruct occupants of air conditioned areas to keep area isolated from non-cooled areas.
f. Keep equipment clean in particular filters and condensers.

f-5/7

g-1

observed environmental conditions

1 ● OBSERVED LIGHT LEVELS IN TWENTY CLASSROOMS

In March 1974 a team of observers visited 20 classrooms in six public schools for the purpose of measuring the light levels under which teachers and students performed their various tasks. The visits were unannounced, and conditions were recorded exactly as found. The six schools represent a cross-section of types of construction and of periods of construction. The oldest school visited was an ornate gothic-style limestone structure built in 1897. The most recently completed school was a curtainwall structure finished in 1968.

Light levels were recorded at ±5'0" intervals in both directions at desk height. Also noted were weather conditions, window locations, sizes of windows, ceiling heights, artificial illumination, fixture patterns, types of fixtures, wattages, and incident light levels at the window sills. Two basic types of lighting fixtures were noted: 1. new and modernized fluorescents, and 2. old five-fixture incandescents.

Observations

The following observations were made:

1. Light intensities were found to be extremely irregular. As reflected in the light contours of the 20 classroom diagrams, light conditions ranged far above, as well as far below currently accepted standards.

Classroom #5 built in 1958 for example, an east-facing classroom, had light levels of 30 fc, 280 fc, 500 fc, 1,000 fc, 350 fc, 2,200 fc measured at 5'0" intervals along a line 5'0" away from the window wall. Along the blackboard to the south the readings ranged from 30 fc to 40 fc. At the west wall 30 fc - 65 fc readings were recorded. Upon further investigation it was found that though the eyes of the observers were not aware of great changes in light levels, meter readings recorded wide fluctuations (incident light level of 500 fc changed to 3,000 fc) due to periods of bright sun interrupted by passing clouds. Artificial il-

lumination was supplied by nineteen 2 tube x 4 foot fluorescent fixtures requiring a total of 1,865 w (2.18 w/sf).

West-facing classroom #6 in the same building had light levels of 65 fc, 110 fc, 200 fc, 180 fc, 130 fc and 32 fc, measuring at 5'0" intervals along a line 5'0" away from the window wall. Readings at the perimeter ranged from 25 fc to 65 fc. Artificial illumination was supplied by eighteen 2 tube x 4 foot fluorescent fixtures requiring a total of 1,767 w (2.43 w/sf).

Classroom #13 built in 1961, a south-facing classroom, had light levels of 100 fc, 260 fc, 180 fc, 450 fc, 210 fc, 400 fc, measured at 5'0" intervals along a line 5'0" away from the window wall. Readings at the north wall ranged from 12 fc to 50 fc. Artificial illumination was supplied by six 4 tube x 4 foot fluorescent fixtures, placed perpendicular to the window wall, requiring a total of 1,116 w (1.39 w/sf).

Classroom #16 built in 1968, a north-facing classroom with incident light levels of 750 fc at the window sill had fc readings of 60 fc, 200 fc, 135 fc, 260 fc, 100 fc measured at 5'0" intervals along a line 5'0" away from the window wall. Along the south wall the readings ranged from 20-50 fc. Artificial illumination was supplied by nine 2 tube x 8 foot fluorescent fixtures, placed in three rows parallel to the window wall, requiring a total of 1,674 w (2.26 w/sf).

Classroom #8 built in 1905, an east-facing classroom, had light levels of 300 fc and 350 fc at the window line and readings of 10 fc, 20 fc, 25 fc, 30 fc, 50 fc along the perimeter of the room. Artificial illumination was supplied by five 160 w fluorescent fixtures which replaced five earlier incandescent fixtures. Total wattage required was 930 w (1.48 w/sf).

2. Light levels were generally unrelated to the tasks being performed. Activities such as drawing, writing and listening were all conducted under the same lighting conditions.

3. With only few exceptions, artificial illumination was in full use, even though daylight (on a clear morning) was adequate in a substantial portion of the classrooms. In most of the classrooms, provisions had been made for deactivating light fixtures along the window walls. However, the switching device was used in only one instance out of the twenty examples. In one of the older classrooms (classroom #11) compensation was made for high daylight levels by reducing the wattage of incandescent fixtures from 200 w at the center and rear of the room to 150 w at the windows.

4. Light control devices were generally used in a haphazard manner, unrelated to actual needs. In several instances, black shades were drawn, cutting off all daylight and making artificial light a necessity. In the older

buildings where high windows make the operation of roller shades more difficult, many blinds were jammed in position. On the other hand, translucent shades were generally well used in the newer buildings to block direct rays of the sun while permitting diffused light to enter.

5. Teachers and students appeared unaware of the wide fluctuations of light intensities.

6. In old and new schools, chalkboards were generally in the darker part of the classrooms. Neither artificial light nor daylight was directed toward the chalkboards.

Note: According to the British government publication, Lighting in Schools, "the chalkboard and any associated display area should be well lit by comparison with the room. At the same time, visual tasks can also be made easier by an increase in contrast or size of details. Thus for the teacher to write on the chalkboard with letters 1½" high instead of 1" high would be as effective in improving visibility as would raising the level of illumination by ten times . . . For a child to move four feet closer to the chalkboard will have visual advantages for him which can only be matched by raising the level of illumination by 30 times. This assumes that distance to chalkboard will be limited to 30 feet". (British standards are based on writing 3/4" high at the blackboard).

SUMMARY: OBSERVED LIGHT LEVELS IN 20 NYC CLASSROOMS

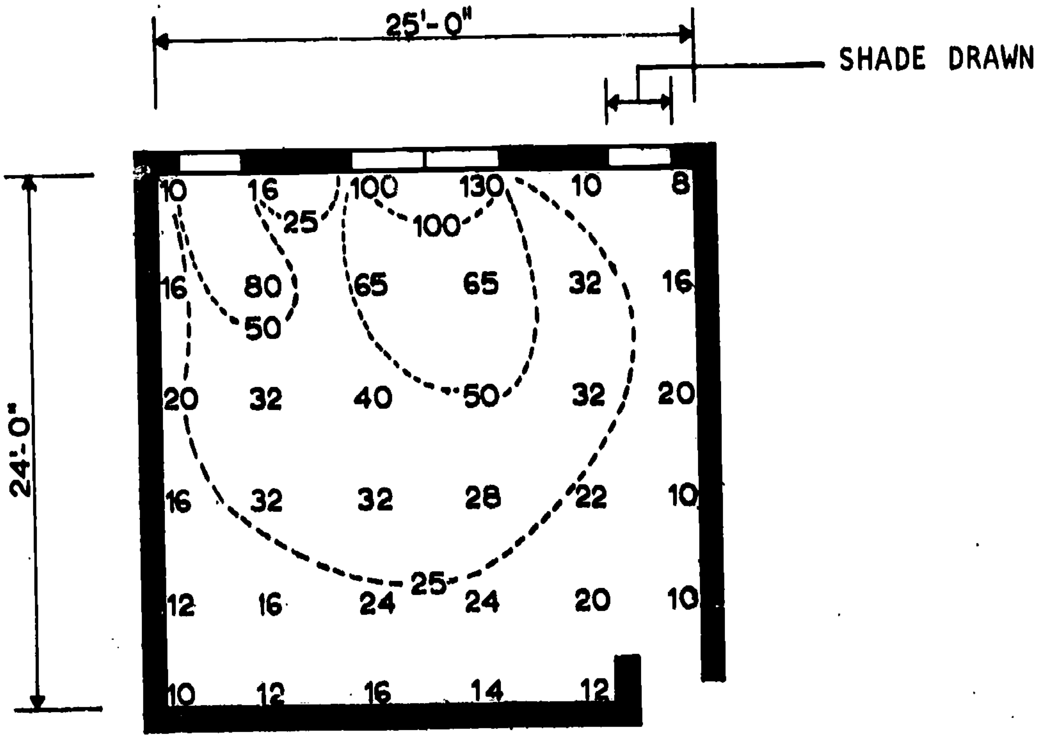
	AREA OF CLASSROOM SF	ARTIFICIAL LIGHT SOURCE	TOTAL WATTAGE IN USE	WATTS/SF	LOWEST LIGHT LEVEL IN FC	INCIDENT LIGHT AT WINDOW SILL IN FC (MAX)	LIGHT LEVEL AT 5 FT FROM WINDOW WALL IN FC (MIN & MAX)
# 1	600	Incandescent	1,000	1.67	6	130	6 - 80
# 2	675	"	1,000	1.48	4	35	10 - 30
# 3	672	"	1,000	1.48	8	85	16 - 65
# 4	701	"	600*	.85	5	180	5 - 110
# 5	852	Fluorescent	1,865	2.18	30	3000	30 -2200
# 6	728	"	1,767	2.43	30	500	32 - 200
# 7	742	"	1,767	2.38	25	450	28 - 180
# 8	627	"	930	1.48	10	350	10 - 90
# 9	624	"	1,116	1.79	8	110	10 - 60
#10	540	"	930	1.72	12	450	70 - 200
#11	600	Incandescent	900	1.50	8	450	30 - 160
#12	746	Fluorescent	1,116	1.50	16	700	75 - 200
#13	805	"	1,116	1.30	12	1900	100 - 450
#14	774	"	1,116	1.44	16	1000	50 - 225
#15	742	"	1,116	1.50	16	500	45 - 160
#16	742	"	1,674	2.26	20	750	60 - 260
#17	745	"	1,674	2.25	16	900	40 - 260
#18	632	Incandescent	1,000	1.58	10	500	2 - 110
#19	594	"	1,000	1.68	10	350	16 - 160
#20	524	"	1,000	1.90	8	450	20 - 160

*not all lights in use

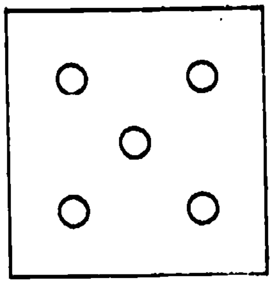
RGS&A-74

FIGURE g-1/1: OBSERVED LIGHT LEVELS IN TWENTY NYC CLASSROOMS

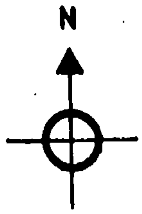
g-1/5
Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN



ELEMENTARY SCHOOL (1897)

3/6/74 9:35 AM
WEATHER: SUNNY, VARIABLE
CEILING HEIGHT: 14'-0"
CHALKBOARD: EAST & WEST WALLS

NATURAL ILLUMINATION

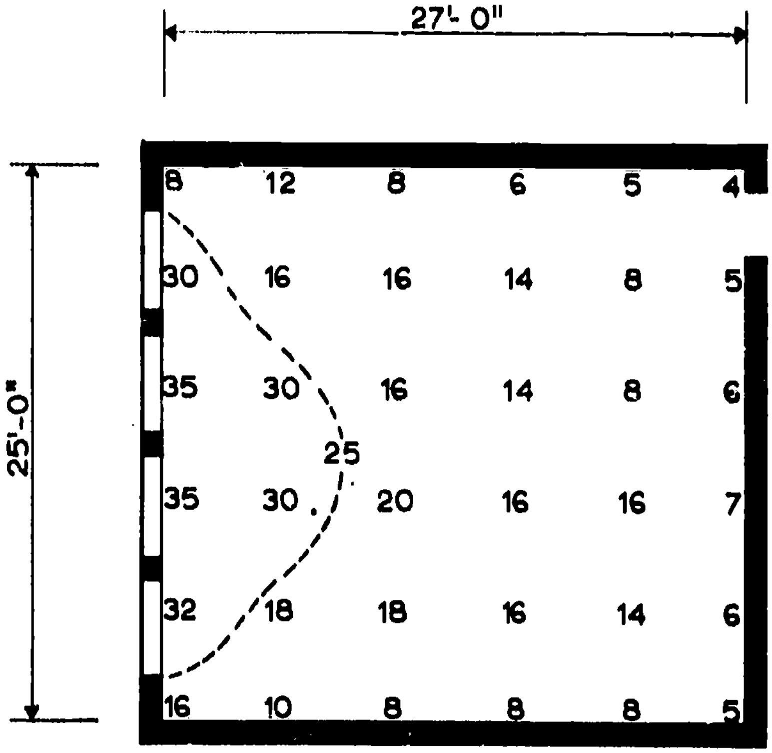
INCIDENT LIGHT AT WINDOW SILL: 130 FC
WINDOWS: 4 @ 3'-0" x 9'-0"

ARTIFICIAL ILLUMINATION

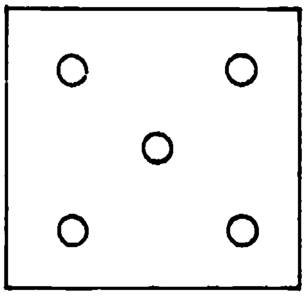
FIXTURES: INCANDESCENT, 5 @ 200W = 1000W
MOUNTING: SUSPENDED @ 10'-0" AFF
LENS: MILK GLASS
2 SWITCHES

FIGURE g-1/2:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 1

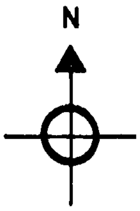
g-1/6
Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN



ELEMENTARY SCHOOL (1897)

3/6/74 9:45 AM
WEATHER: SUNNY, VARIABLE
CEILING HEIGHT: 14'-0"
CHALKBOARD: NORTH WALL

NATURAL ILLUMINATION

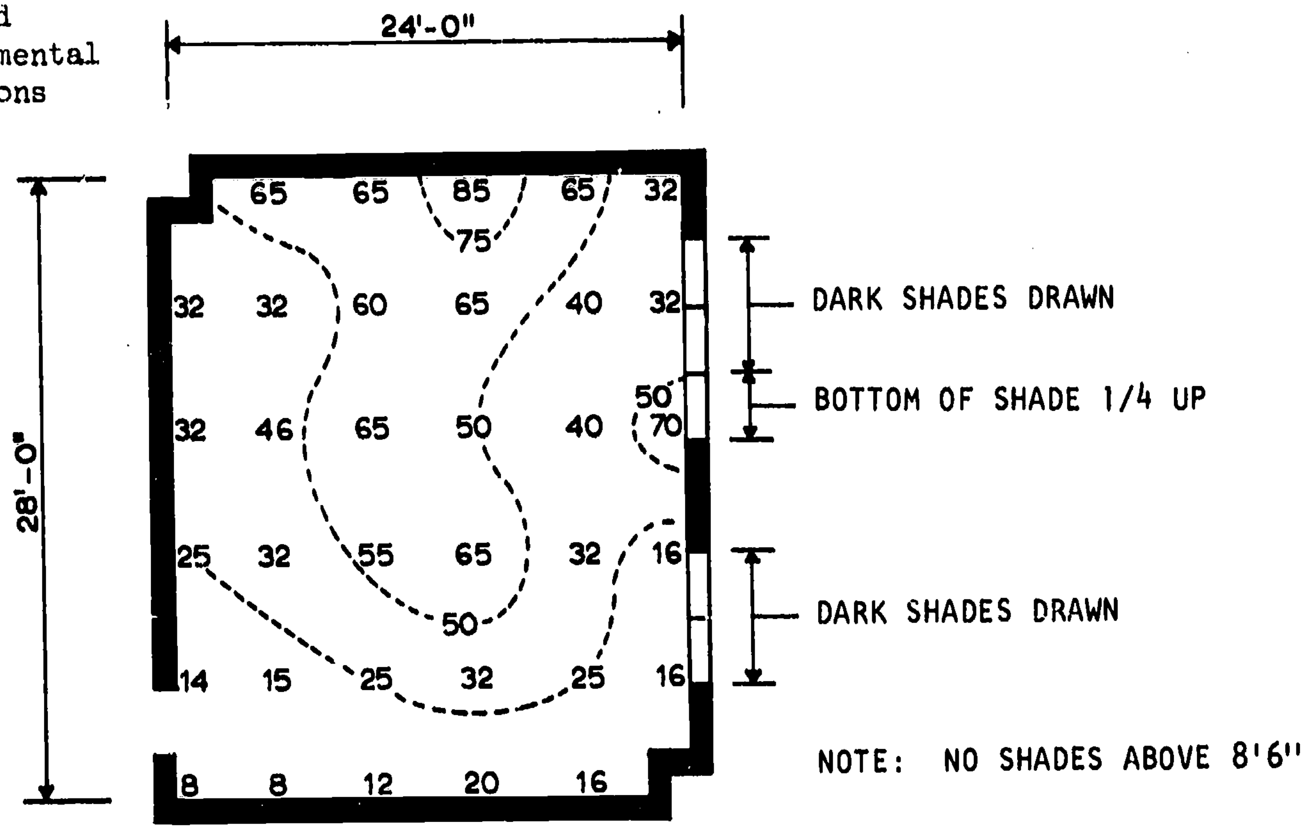
INCIDENT LIGHT AT WINDOW SILL: 38 FC
WINDOWS: 4 @ 4'-6" x 10'-0"

ARTIFICIAL ILLUMINATION

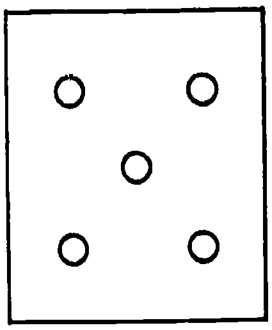
FIXTURES: INCANDESCENT, 5 @ 200W = 1000W
MOUNTING: SUSPENDED @ 10'-0" AFF
LENS: MILK GLASS
2 SWITCHES

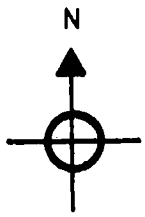
FIGURE g-1/3:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 2

g-1/7
Observed
Environmental
Conditions



FC READINGS





FIXTURE PATTERN

ELEMENTARY SCHOOL (1897)

3/6/74 10:00 AM
WEATHER: SUNNY, VARIABLE
CEILING HEIGHT: 14'-0"
CHALKBOARD: SOUTH WALL

NATURAL ILLUMINATION

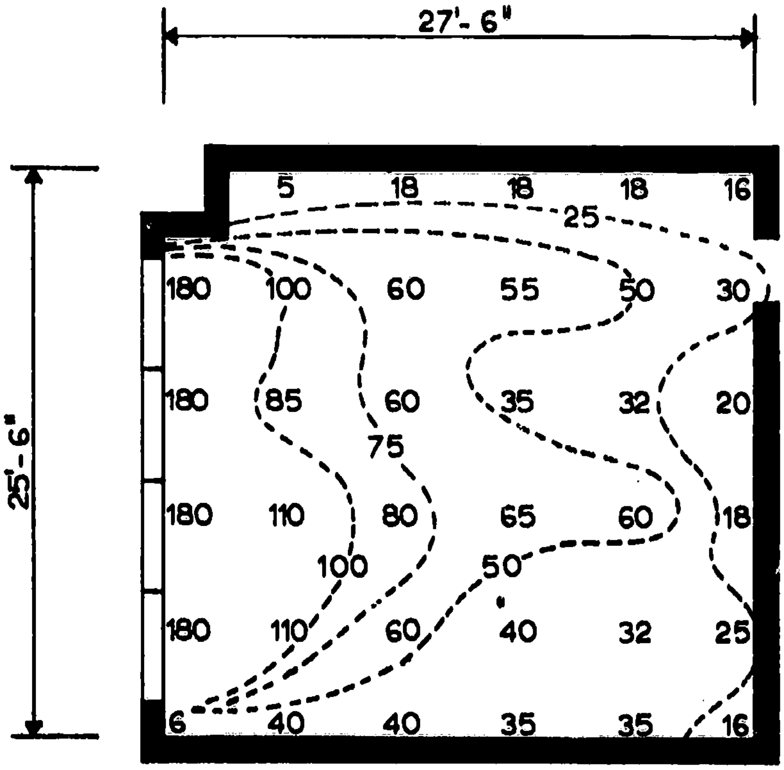
INCIDENT LIGHT AT WINDOW SILL: 3000 FC
WINDOW DIMENSIONS: 5 @ 2'-6" x 10'-0"

FIGURE g-1/4:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 3

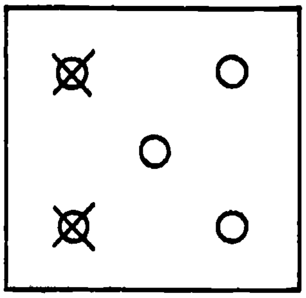
ARTIFICIAL ILLUMINATION

FIXTURES: INCANDESCENT, 5 @ 200W = 1000W
MOUNTING: SUSPENDED @ 10'-0" AFF
LENS: MILK GLASS
2 SWITCHES

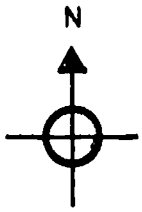
g-1/8
Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN



ELEMENTARY SCHOOL (1897)

3/6/74 10:15 AM
WEATHER: SUNNY, VARIABLE
CEILING HEIGHT: 14'-0"
CHALKBOARD: NORTH WALL

NATURAL ILLUMINATION

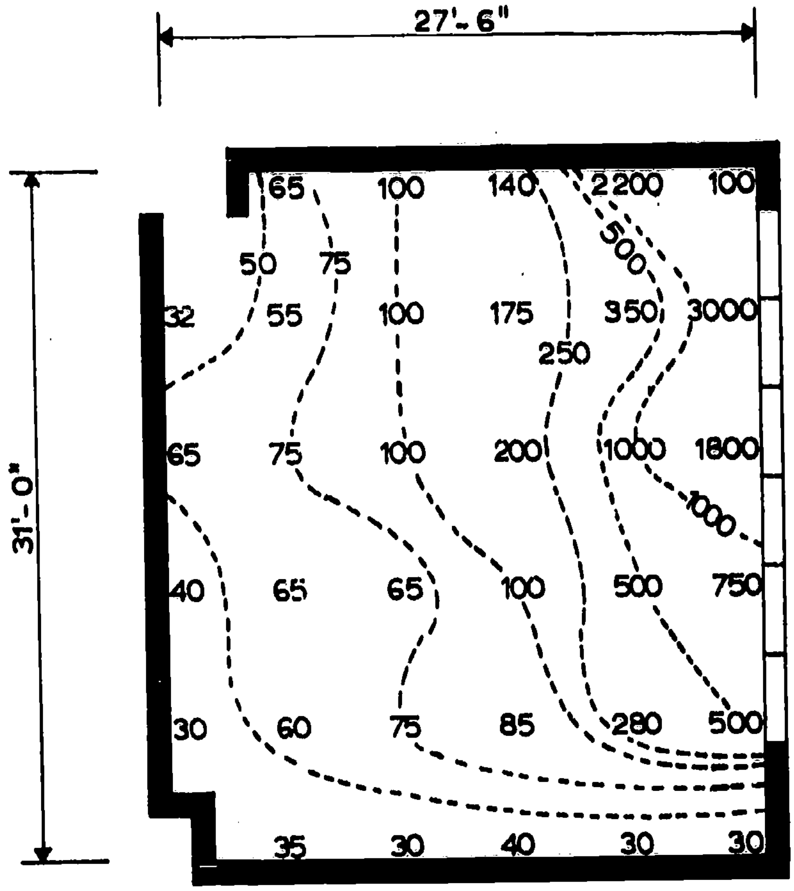
INCIDENT LIGHT AT WINDOW SILL: 180 FC
WINDOWS: 4 @ 4'-6" x 10'-0"

ARTIFICIAL ILLUMINATION

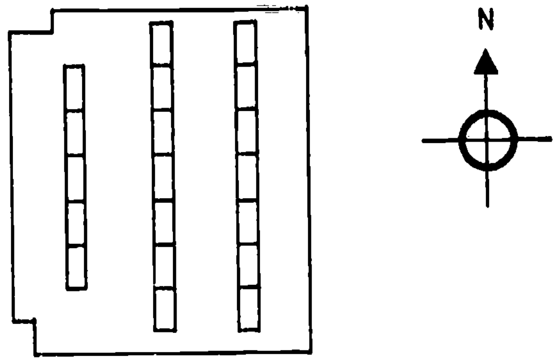
FIXTURES: INCANDESCENT, 5 @ 200W = 1000W
3 FIXTURES LIGHTED = 600W
MOUNTING: SUSPENDED @ 10'-0" AFF
LENS: MILK GLASS
2 SWITCHES

FIGURE g-1/5:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 4

g-1/9
Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN

ELEMENTARY SCHOOL (1958)

3/6/74 10:35 AM
WEATHER: SUNNY, PASSING CLOUDS
CEILING HEIGHT: 11'-2"
CHALKBOARD: SOUTH WALL

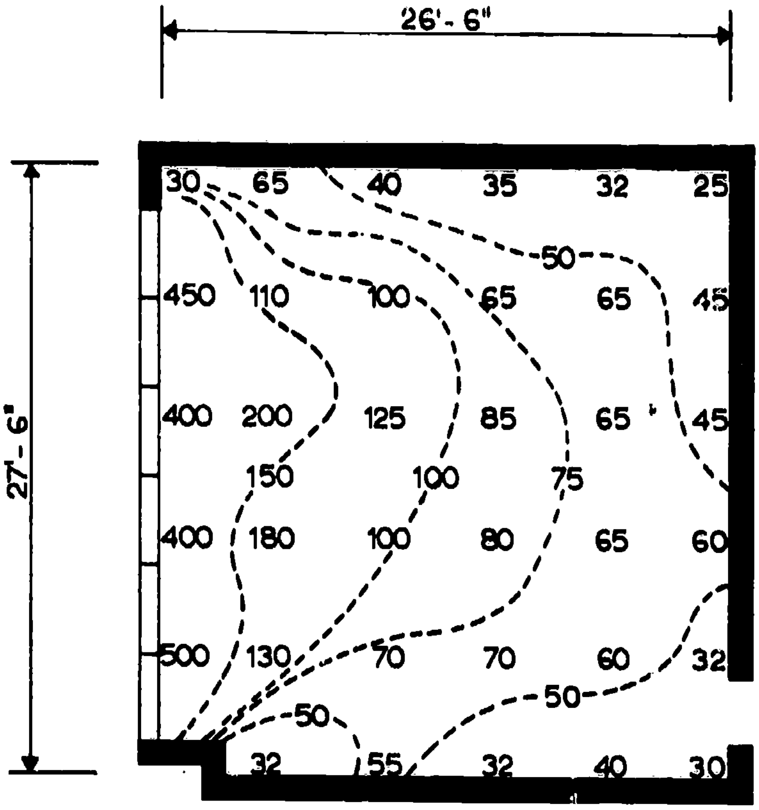
NATURAL ILLUMINATION

INCIDENT LIGHT AT WINDOW SILL: 750 - 3000 FC
WINDOWS: 6 @ 4' x 6'-4"

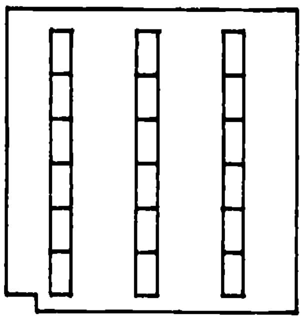
FIGURE g-1/6:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 5

ARTIFICIAL ILLUMINATION

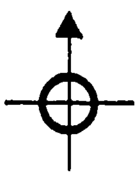
FIXTURES: FLUORESCENT, 19 @ 93W (2-48" TUBES) = 1767W
MOUNTING: SUSPENDED @ 8'-9" AFF
LENS: EGG CRATE LOUVER
2 SWITCHES



FC READING



FIXTURE PATTERN



ELEMENTARY SCHOOL (1958)

3/6/74 11:00 AM
WEATHER: SUNNY, PASSING CLOUDS
CEILING HEIGHT: 10'-0"
CHALKBOARD: NORTH WALL

NATURAL ILLUMINATION

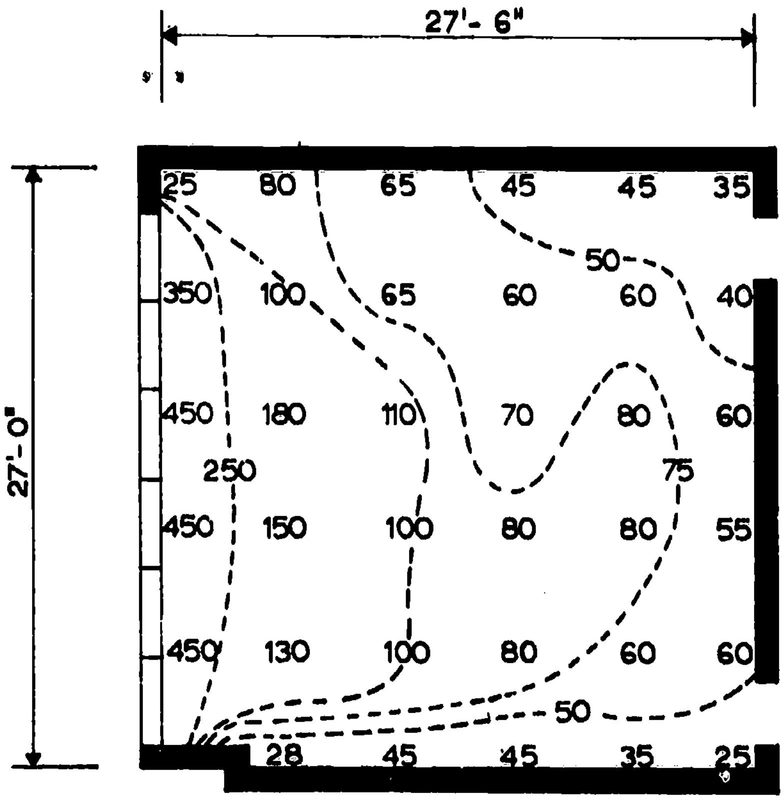
INCIDENT LIGHT AT WINDOW SILL: 400 - 500 FC
WINDOWS: 6 @ 4' x 6'-4"

ARTIFICIAL ILLUMINATION

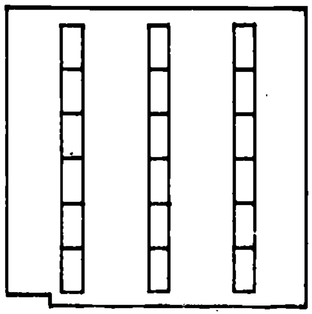
FIGURE g-1/7:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 6

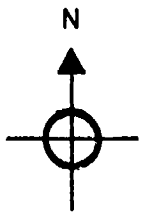
FIXTURES: FLUORESCENT, 18 @ 93W (2-48" TUBES) = 1767W
MOUNTING: SUSPENDED @ 8'-9" AFF
LENS: EGG CRATE LOUVER
2 SWITCHES

g-1/11
Observed
Environmental
Conditions



FC READINGS





FIXTURE PATTERN

ELEMENTARY SCHOOL (1958)

3/6/74 11:15 AM
WEATHER: SUNNY, PARTIAL OVERCAST
CEILING HEIGHT: 10-0"
CHALKBOARD: NORTH WALL

NATURAL ILLUMINATION

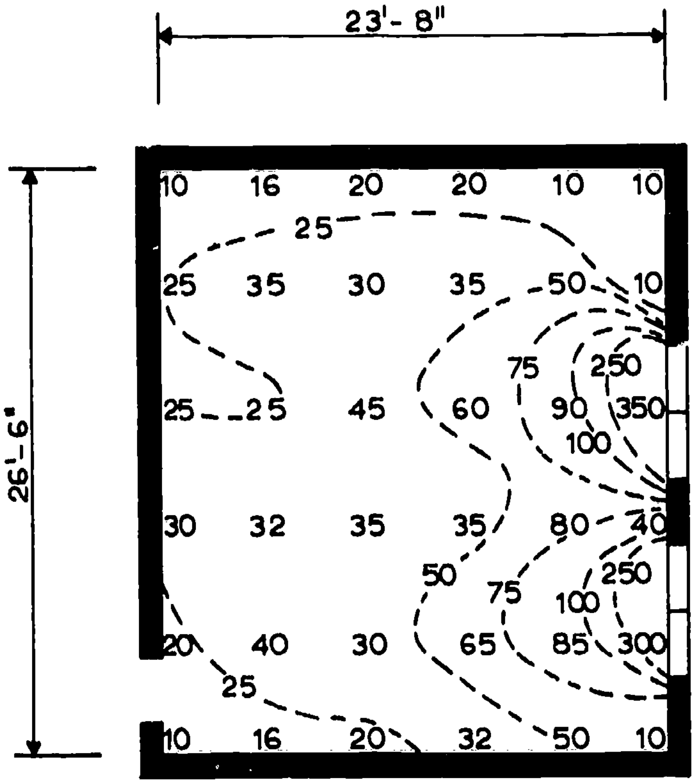
INCIDENT LIGHT AT WINDOW SILL: 350 - 450 FC
WINDOWS: 6 @ 4' x 6'-4"

ARTIFICIAL ILLUMINATION

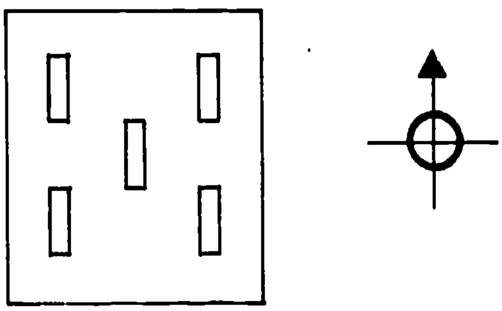
FIXTURES: FLUORESCENT 18 @ 93W (2-48"TUBES) = 1767W
MOUNTING: SUSPENDED @ 8'-9" AFF
LENS: EGG CRATE LOUVER
2 SWITCHES

FIGURE g-1/8:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 7

g-1/12
Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN

ELEMENTARY SCHOOL (1905)

3/6/74 11:30 AM
WEATHER: OVERCAST
CEILING HEIGHT: 14'-0"
CHALKBOARD: SOUTH WALL

NATURAL ILLUMINATION

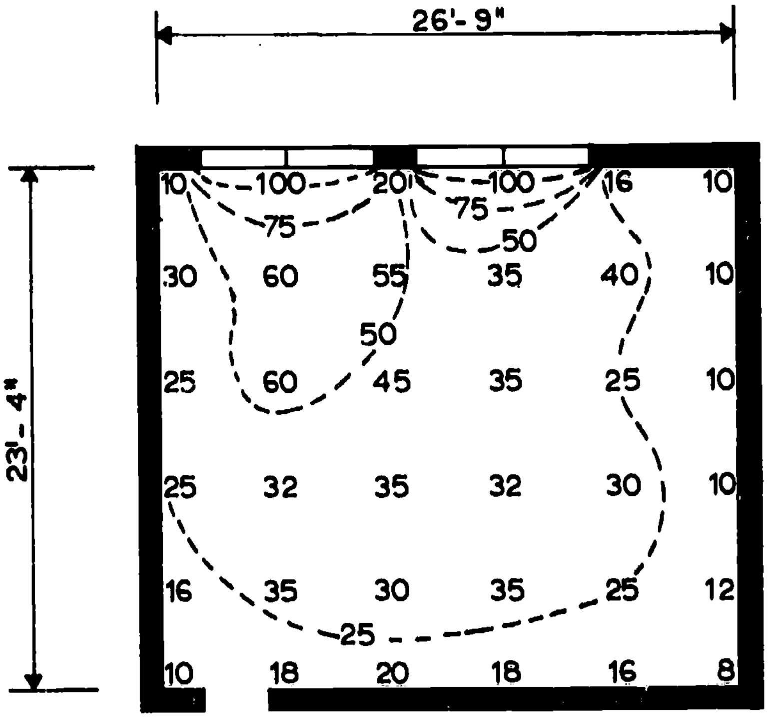
INCIDENT LIGHT AT WINDOW SILL: 350 FC
WINDOWS: 3' x 10'-6"

ARTIFICIAL ILLUMINATION

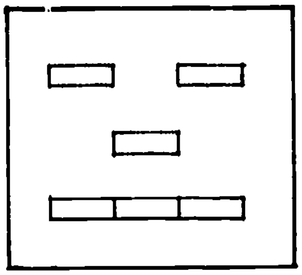
FIXTURES: FLUORESCENT, 5 @ 186W (4-48" TUBES) = 930W
MOUNTING: SUSPENDED @ 10'-6" AFF
LENS: 1/2" x 1/2" LOUVER
2 SWITCHES

FIGURE g-1/9:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 8

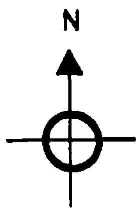
g-1/13
Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN



ELEMENTARY SCHOOL (1905)

3/6/74 11:45 AM
WEATHER: PARTIAL OVERCAST
CEILING HEIGHT: 14'-0"
CHALKBOARD: EAST WALL

NATURAL ILLUMINATION

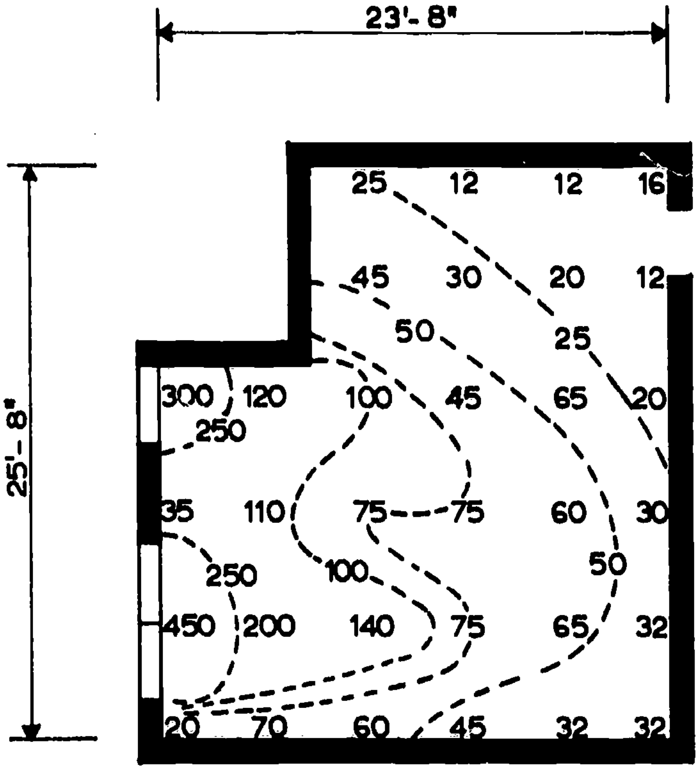
INCIDENT LIGHT AT WINDOW SILL: 110 FC
WINDOWS: 3'-8" x 9'-4"

ARTIFICIAL ILLUMINATION

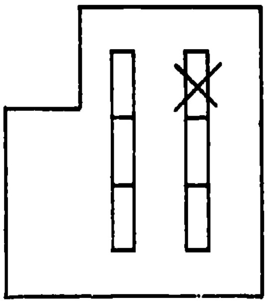
FIXTURES: FLUORESCENT, 6 @ 186W (4-48" TUBES) = 1116W
MOUNTING: SUSPENDED @ 10'-6" AFF
LENS: 1/2" x 1/2" LOUVER
2 SWITCHES

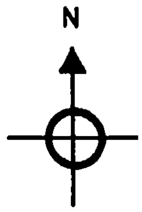
FIGURE g-1/10:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 9

g-1/14
Observed
Environmental
Conditions



FC READINGS





FIXTURE PATTERN

ELEMENTARY SCHOOL (1905)

3/6/74 12:00
WEATHER: SUNNY, PARTIAL OVERCAST
CEILING HEIGHT: 14'-0"

NATURAL ILLUMINATION

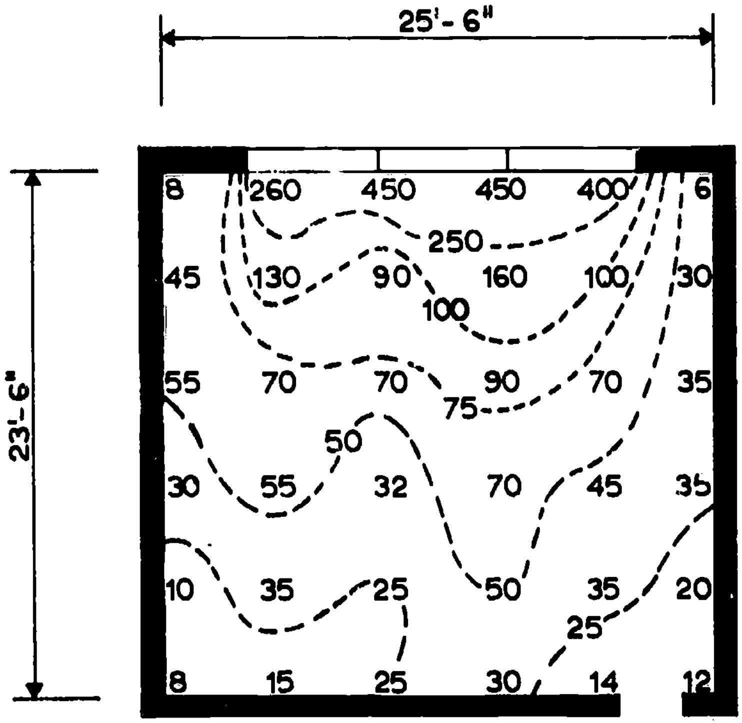
INCIDENT LIGHT AT WINDOWS SILL: 300 - 450 FC
WINDOWS: 3'-6" x 10-0"

ARTIFICIAL ILLUMINATION

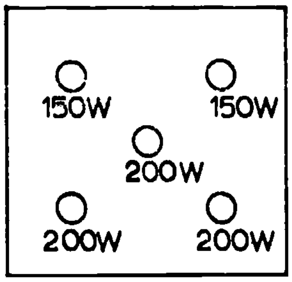
FIXTURES: FLUORESCENT, 6 @ 186W(2-96" TUBES) = 1116W
5 FIXTURES LIGHTED = 930W
MOUNTING: SUSPENDED @ 10'-0" AFF
LENS: EGG CRATE LOUVER
2 SWITCHES

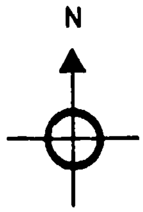
FIGURE g-1/11:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 10

g-1/15
Observed
Environmental
Conditions



FC READINGS





FIXTURE PATTERN

ELEMENTARY SCHOOL (1905)

3/6/74 12:15 PM
WEATHER: PARTIAL OVERCAST
CEILING HEIGHT: 13'-6"
CHALKBOARD: EAST & WEST WALLS

NATURAL ILLUMINATION

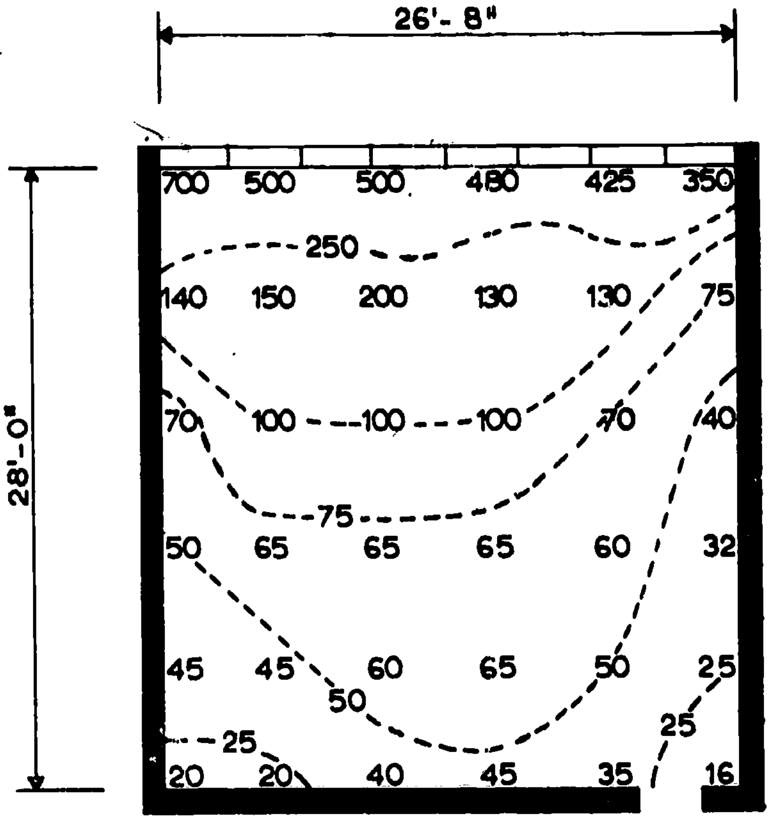
INCIDENT LIGHT AT WINDOW SILL: 260 - 450 FC
WINDOWS: 5'-6" x 10'-0"

ARTIFICIAL ILLUMINATION

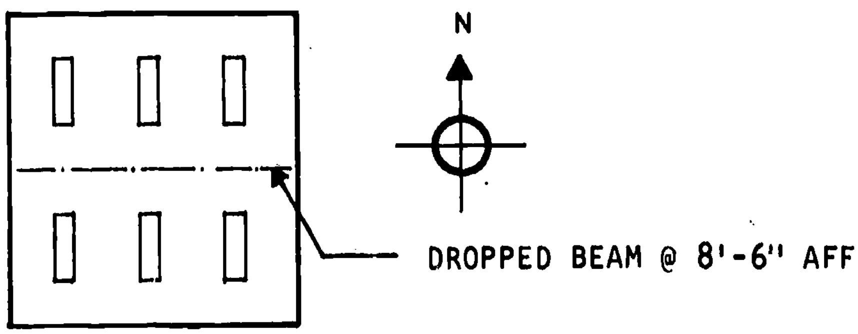
FIXTURES: INCANDESCENT, 5 AS SHOWN = 900W
MOUNTING: SUSPENDED @ 9'-0" AFF
LENS: MILK GLASS
2 SWITCHES

FIGURE g-1/12:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 11

Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN

FIGURE g-1/13:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 12

ELEMENTARY SCHOOL (1961)

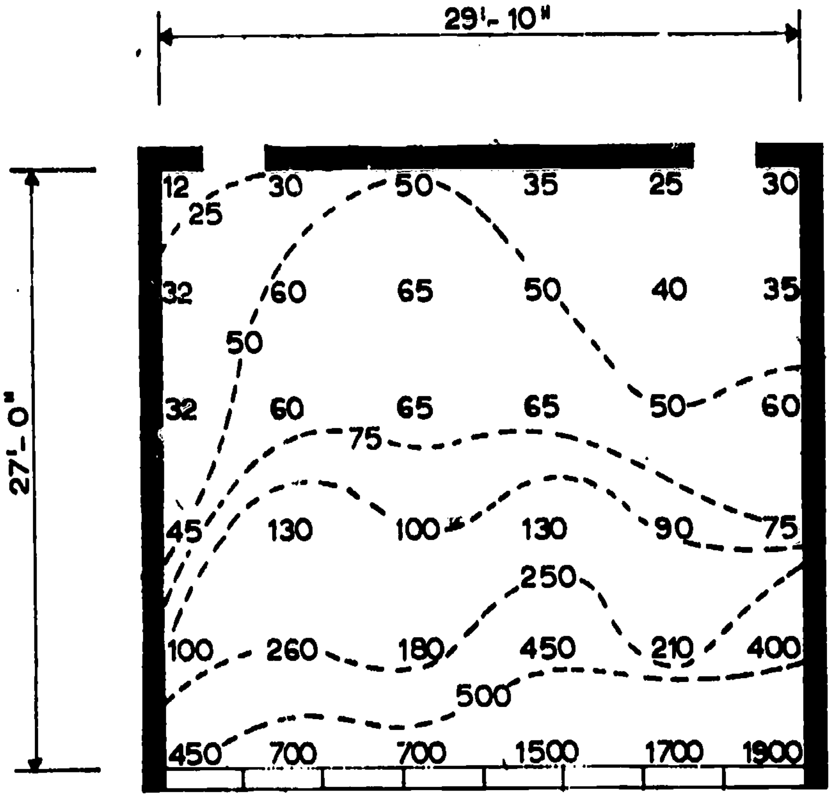
3/6/74 1:25 PM
WEATHER: PARTLY OVERCAST
CEILING HEIGHT: 9'-6"
CHALKBOARD: EAST WALL

NATURAL ILLUMINATION

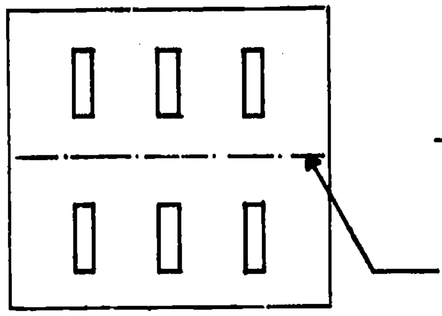
INCIDENT LIGHT AT WINDOW SILL: 350 - 700 FC
WINDOWS: 3'-4" x 5'-6"

ARTIFICIAL ILLUMINATION

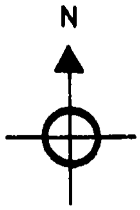
FIXTURES: FLUORESCENT, 6 @ 186W (2-96" TUBES) = 1116W
MOUNTING: SUSPENDED @ 8'-6" AFF
LENS: EGG CRATE LOUVER
2 SWITCHES



FC READINGS



FIXTURE PATTERN



ELEMENTARY SCHOOL (1961)

3/6/74 1:40 PM
WEATHER: SUNNY & OVERCAST
CEILING HEIGHT: 9'-6"
CHALKBOARD: WEST WALL

NATURAL ILLUMINATION

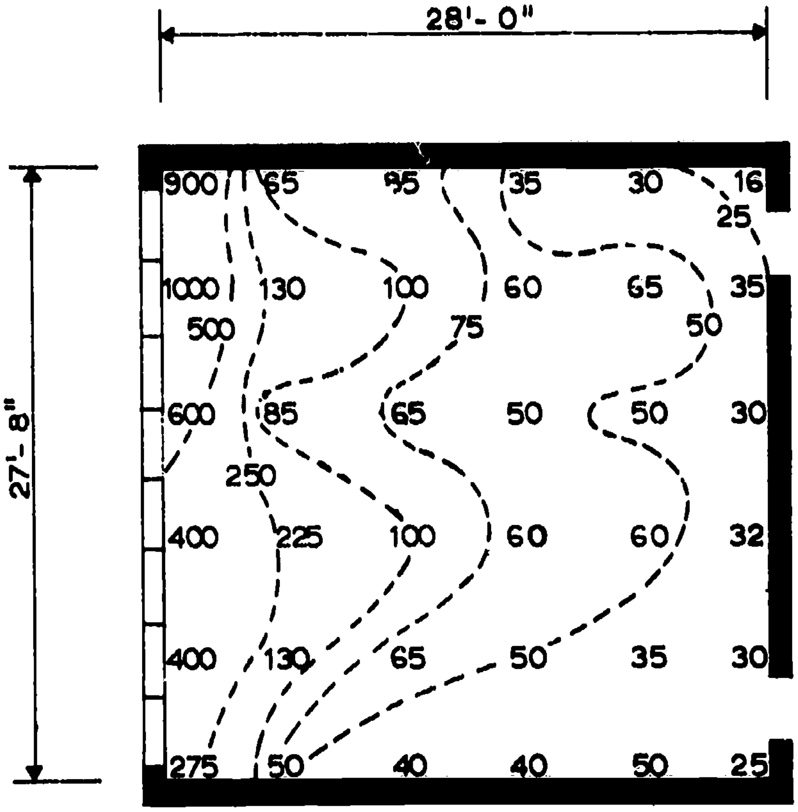
INCIDENT LIGHT AT WINDOW SILL: 450 - 1900 FC
WINDOWS: 3'-4" x 5'-6"

ARTIFICIAL ILLUMINATION

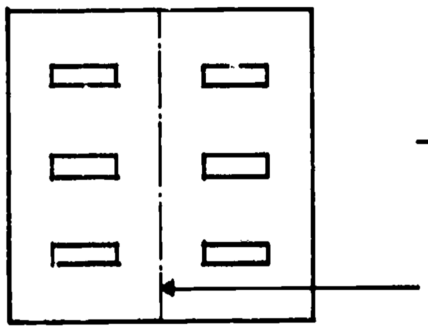
FIXTURES: FLUORESCENT, 6 @ 186W (2-96" TUBES) = 1116W
MOUNTING: SUSPENDED @ 8'-6" AFF
LENS: EGG CRATE LOUVER
2 SWITCHES

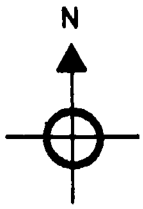
FIGURE g-1/14:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 13

g-1/18
Observed
Environmental
Conditions



FC READINGS





FIXTURE PATTERN

ELEMENTARY SCHOOL (1961)

3/6/74 1:50 PM
WEATHER: OVERCAST, VARIABLE
CEILING HEIGHT: 9'-6''
CHALKBOARD: NORTH WALL

NATURAL ILLUMINATION

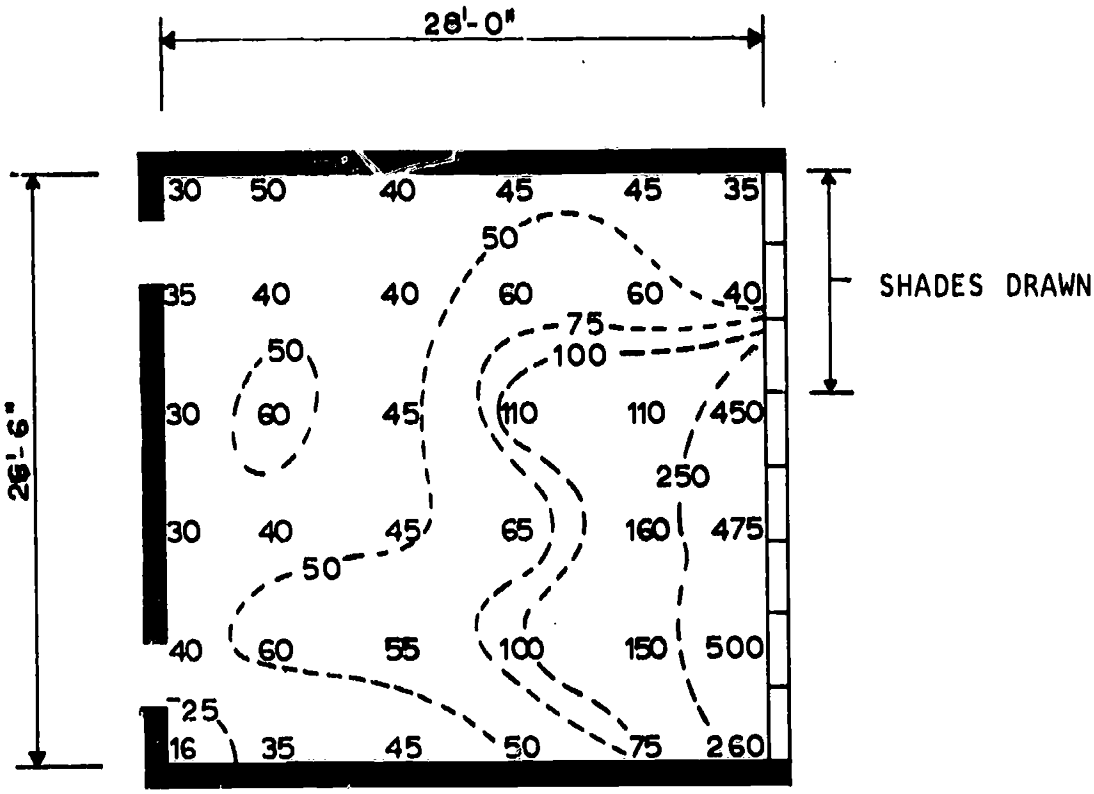
INCIDENT LIGHT AT WINDOW SILL: 275 - 1000 FC
WINDOWS: 3'-4'' x 5'-6''

FIGURE g-1/15:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 14

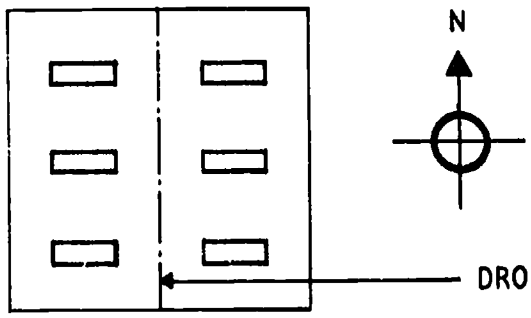
ARTIFICIAL ILLUMINATION

FIXTURES: FLUORESCENT, 6 @ 186W (2-96'' TUBES) = 1116W
MOUNTING: SUSPENDED @ 8'-6'' AFF
LENS: EGG CRATE LOUVER
2 SWITCHES

g-1/19
Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN

ELEMENTARY SCHOOL (1961)

3/6/74 2:00 PM
WEATHER: OVERCAST, VARIABLE
CEILING HEIGHT: 9'-6"
CHALKBOARD: SOUTH WALL

NATURAL ILLUMINATION

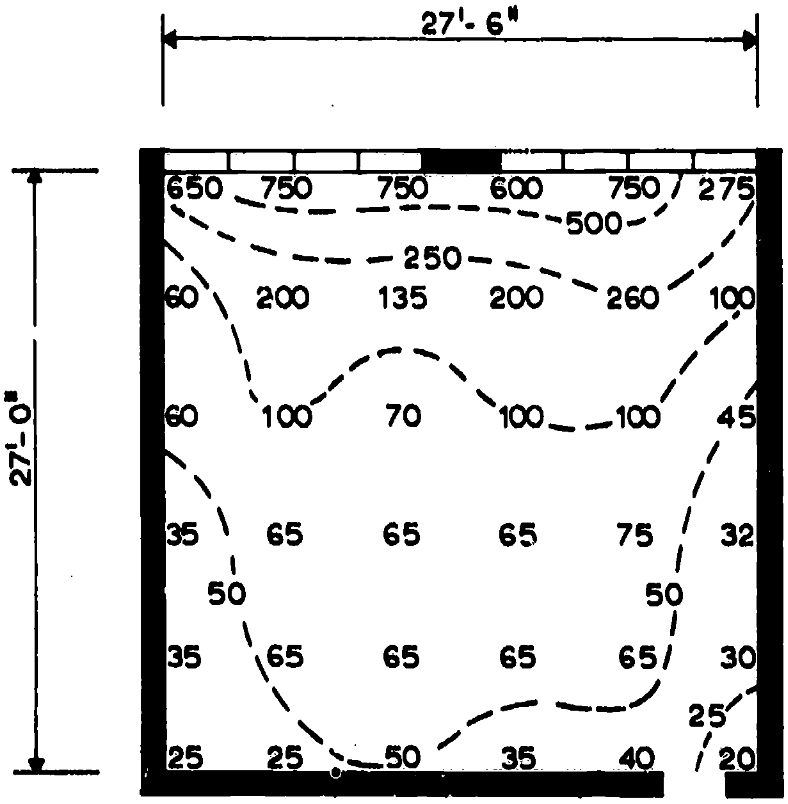
INCIDENT LIGHT AT WINDOW SILL: 260 - 500 FC
WINDOWS: 3'-4" x 5'-6"

ARTIFICIAL ILLUMINATION

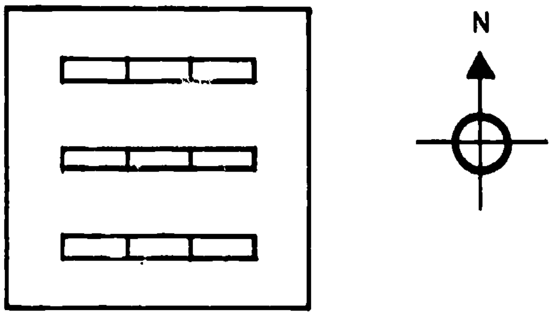
FIXTURES: FLUORESCENT, 6 @ 186W (2-96" TUBES) = 1116W
MOUNTING: SUSPENDED @ 8'-6" AFF
LENS: EGG CRATE LOUVER
2 SWITCHES

FIGURE g-1/16:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 15

g-1/20
Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN

ELEMENTARY SCHOOL (1968)

3/6/74 2:15 PM
WEATHER: CLOUDY, VARIABLE
CEILING HEIGHT: 10'-3"
CHALKBOARD: EAST WALL

NATURAL ILLUMINATION

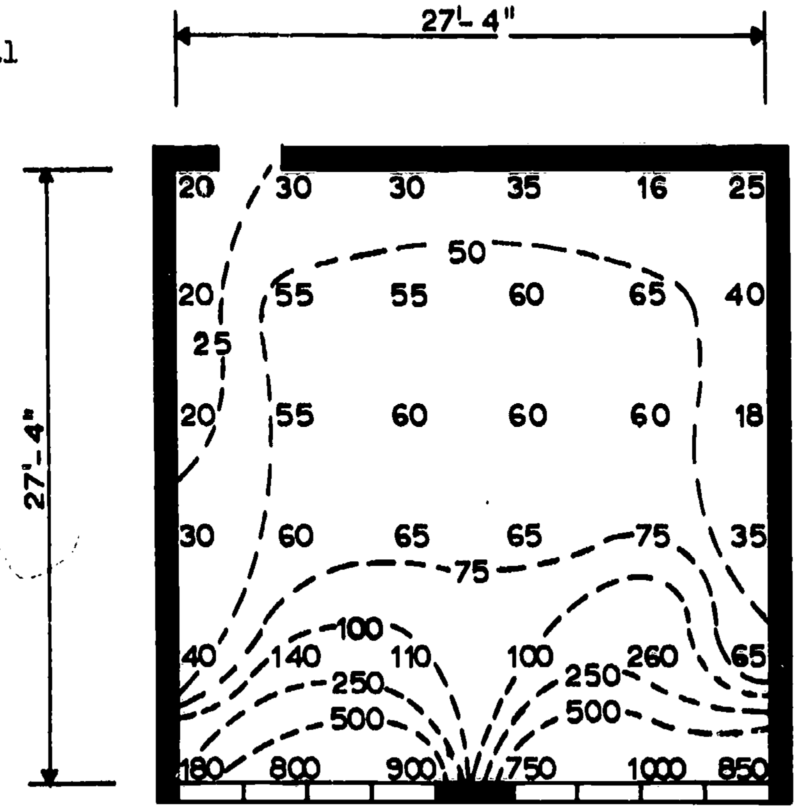
INCIDENT LIGHT AT WINDOW SILL: 275 - 750 FC
WINDOWS: 3'-0" x 6'-0"

ARTIFICIAL ILLUMINATION

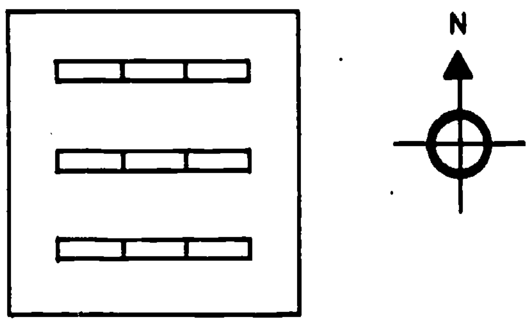
FIXTURES: FLUORESCENT, 9 @ 186W (2-96" TUBES) = 1674W
MOUNTING: SUSPENDED @ 8'-6" AFF
LENS: EGG CRATE LOUVER
2 SWITCHES

FIGURE g-1/17:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 16

g-1/21
Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN

JUNIOR HIGH SCHOOL (1968)

3/6/74   2:30 PM
WEATHER: VARIABLE
CEILING HEIGHT: 8'-8"
CHALKBOARD: WEST WALL

NATURAL ILLUMINATION

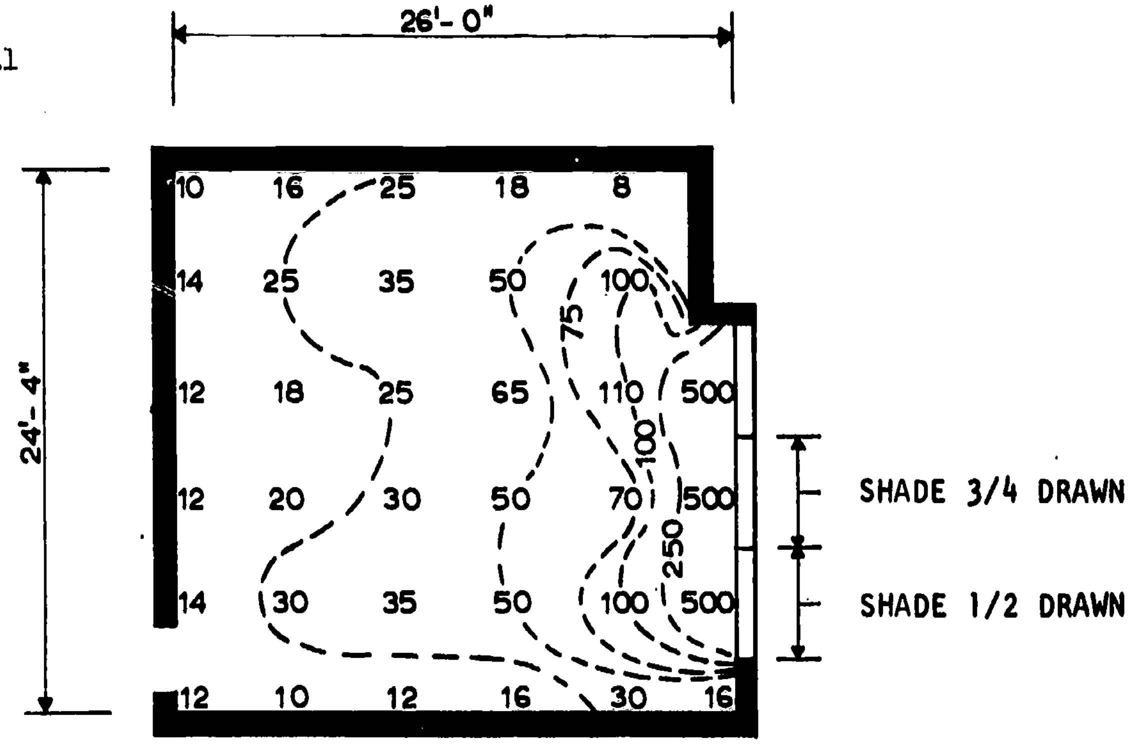
INCIDENT LIGHT AT WINDOW SILL: 180 - 1000 FC
WINDOWS: 3'-0" x 6'-0"

ARTIFICIAL ILLUMINATION

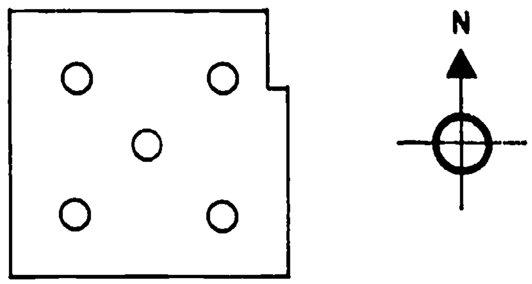
FIXTURES: FLUORESCENT, 9 @ 186W (2-96" TUBES) = 1674W
MOUNTING: SUSPENDED @ 8'-2" AFF
LENS: EGG CRATE LOUVER
2 SWITCHES

FIGURE g-1/18:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 17

g-1/22
Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN

HIGH SCHOOL (1904)

3/6/74 3:00 PM
WEATHER: VARIABLE
CEILING HEIGHT: 14'-0"
CHALKBOARD: SOUTH WALL

NATURAL ILLUMINATION

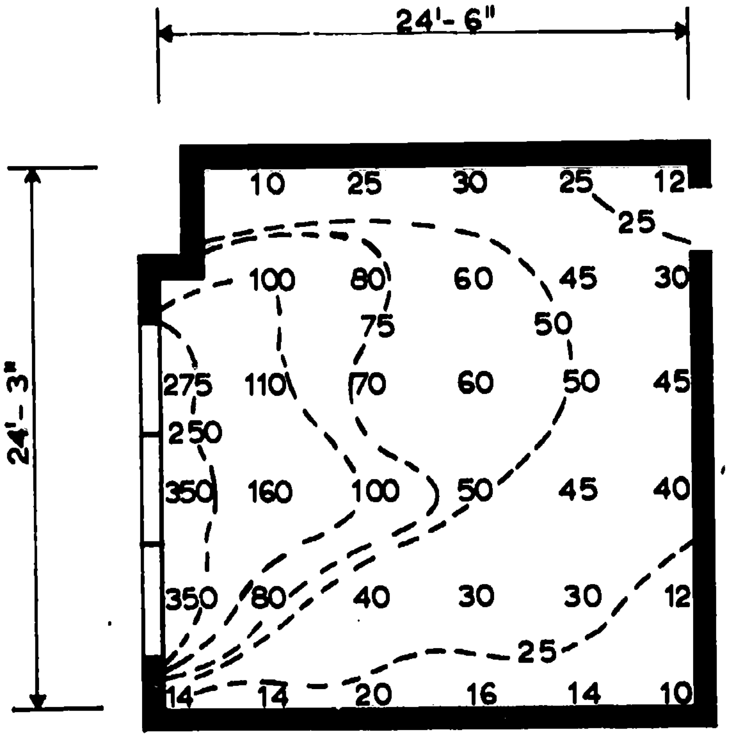
INCIDENT LIGHT AT WINDOW SILL: 500 FC
WINDOWS: 5'-0" x 11'-0"

ARTIFICIAL ILLUMINATION

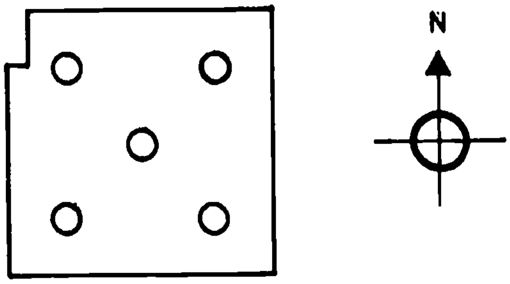
FIXTURES: INCANDESCENT, 5 @ 200W = 1000W
MOUNTING: SUSPENDED @ 8'-6" AFF
LENS: MILK GLASS
2 SWITCHES

FIGURE g-1/19:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 18

g-1/23
Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN

HIGH SCHOOL (1904)

3/6/74 3:15 PM
WEATHER: OVERCAST, VARIABLE
CEILING HEIGHT: 14'-0"
CHALKBOARD: NORTH & SOUTH WALLS

NATURAL ILLUMINATION

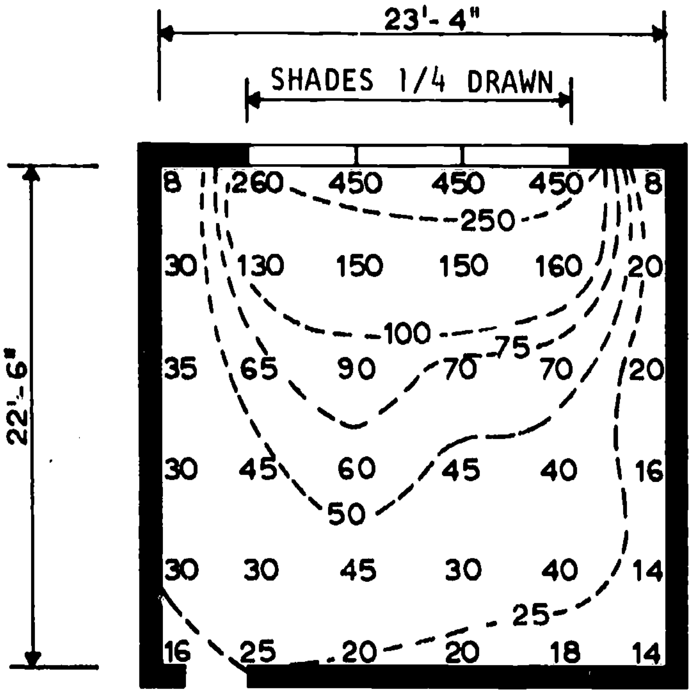
INCIDENT LIGHT AT WINDOW SILL: 275 - 350 FC
WINDOWS: 5'-0" x 10'-0"

ARTIFICIAL ILLUMINATION

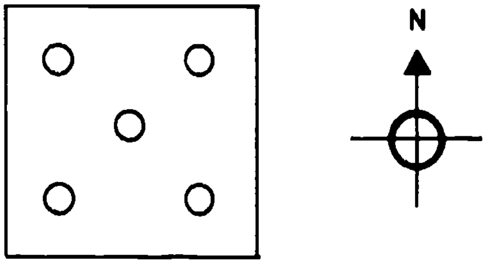
FIXTURES: INCANDESCENT, 5 @ 200W = 1000W
MOUNTING: SUSPENDED @ 8'-6" AFF
LENS: MILK GLASS
2 SWITCHES

FIGURE g-1/20:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 19

Observed
Environmental
Conditions



FC READINGS



FIXTURE PATTERN

HIGH SCHOOL (1904)

3/6/74 3:30 PM
WEATHER: OVERCAST, VARIABLE
CEILING HEIGHT: 14'-0"
CHALKBOARD: EAST WALL

NATURAL ILLUMINATION

INCIDENT LIGHT AT WINDOW SILL: 260 - 450 FC
WINDOWS: 5' 0" x 11'-0"

ARTIFICIAL ILLUMINATION

FIXTURES: INCANDESCENT, 5 @ 200W = 1000W
MOUNTING: SUSPENDED @ 8'-6" AFF
LENS: MILK GLASS
2 SWITCHES

FIGURE g-1/21:
OBSERVED
LIGHT LEVELS
CLASSROOM NO. 20

g-2

observed environmental conditions

2 ● ANALYSIS OF OBSERVED VENTILATION PERFORMANCE

It is apparent from the figures presented in sub-report f on Fuel and Electricity Use in New York City Schools, that the re-evaluation of outside air requirements offers the possibility of substantial energy savings. In order to do this, it is necessary to redefine the reasons for introducing outside air.

Life support: A certain quantity of air is required to replace oxygen consumed by respiration and to dissipate carbon dioxide and other by-products of respiration.

Odor control: Outside air is required to dissipate disagreeable odors.

Thermal control: Outside air is introduced in order to dissipate internal or solar heat gain tending to raise interior temperatures above the desired maximum level. (Note: this is only effective when outside temperatures are lower than inside temperatures).

A series of studies have been carried out which indicate that under normal conditions life support and odor control can be satisfied by the introduction of 5 cfm/occupant in enclosed spaces where smoking or strenuous activity does not take place. It should be noted that this measure includes numerous safety factors:

1. No credit is taken for the introduction of air into classrooms during period breaks when doors are opened and closed.

2. No credit is taken for the "recharging" of the entire building due to infiltration when it is unoccupied during the night and on weekends.

3. The actual calculated requirement for O_2 and CO_2 control in classroom is about 2.38 cfm/occupant, adding a 100

percent safety factor on top of the other considerations (see Nevins Study on the following pages).

Where a high degree of activity is anticipated, the introduction of 15 cfm/active occupant should be provided. The differentiation between active and passive occupant becomes important in the case of gymnasiums, for example, where some occupants will be highly active; however, there may be a large number of spectators who will be relatively passive. In setting ventilation rates, consideration should be given to the fact that one space can be anticipated to have two kinds of occupancy simultaneously.

The basic ventilation rates indicated above will be required whenever the space in question is occupied regardless of heating or cooling demands. They become the basic standards for outside air introduction. Additional outside air for cooling may be required at times. This should be introduced by either varying the output of the base system or by wholly independent means. In either case, the control for this additional air should be handled in a way reflecting the conditions which call for the increase, that is, it should be responsive to internal and external temperatures. Manually controlled operable windows actually work in this way. The occupants of a space act as the sensing and the operating mechanisms. When they feel warm, they open a window causing an increase in outside air to enter. The exact quantity of this increase is difficult to predict exactly; however, experience and generally accepted formulas indicate that, given moderate proportions of operable window area to floor area (say five to ten percent), the amount will be under most circumstances greater than the standards currently set.

In the middle of April of this year, the National Bureau of Standards in cooperation with this study conducted a series of tests in a classroom in a New York City school. The ventilation rates were varied from day to day. The temperature, relative humidity, oxygen and carbon dioxide levels were continuously monitored and recorded. The rate of exhaust at the grilles was measured when one or more grilles were operating and the rate of air change was measured for various conditions. In addition, a trained psychologist observed each class to determine whether any noticable signs of discomfort were exhibited by the occupants and whether any disagreeable odors could be detected. The results which are contained in a companion report by the National Bureau of Standards indicate that all conditions under consideration were entirely adequate when outside air was entering the room at rates as low as 4 cfm/occupant allowing a 100 percent safety factor.

Dr. Ralph G. Nevins, who has been active in the field of environmental conditions and human response for many years and whose work has been the basis for numerous standards, including a sizable role in the latest ASHRAE recommendations has prepared a survey of criteria for school ventilation. This survey included as part of this sub-report, indicates that

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5 cfm is sufficient to conform with all health and safety requirements. Under most conditions, open windows will provide more outside air than is currently specified under existing standards for mechanically supplied outside air.

NEVINS STUDY

The minimum requirements for introduction of outside air into an enclosed space are based on oxygen replacement and carbon dioxide removal requirements resulting from respiration. Sufficient fresh air must be supplied to the space to maintain an adequate concentration of oxygen and to dilute the carbon dioxide which is produced as a product of the respiration. Table 1 indicates the approximate relationship between physical activity, energy expenditure, oxygen consumption, carbon dioxide production and the rate of breathing (1)*.

Table 1 Energy Expenditure, Oxygen Consumption, Carbon Dioxide Production & Rate of Breathing of Men

Activity	Energy Expenditure btuh	Oxygen Consumption cfh	Carbon Dioxide Production cfh	Rate of Breathing cfh
Prone, rest	300	0.60	0.50	15
Seated, Sedentary	400	0.80	0.67	20
Strolling	600	1.20	1.00	30
Walking 3 mph	1000	2.00	1.67	50

As early as 1883, Hermans of Amsterdam demonstrated clearly that the air of a chamber containing only 15% of oxygen and 2%-4% of carbon dioxide was not toxic (2). Other investigators in the United States, Germany and England confirmed these findings. Landsberg (3) recommends as specification for adequate air quality an oxygen content of 18%-21% and a carbon dioxide content of 0.6% as a maximum figure. The range of oxygen content coincides with the possible variations in ambient air oxygen partial pressure which occurs

* Numbers in parenthesis refer to references listed at end of the report.

Observed Environmental Conditions

natually due to fluctuation in barometric pressure or with a change in altitude. At sea level, where the normal barometric pressure is 760 mm Hg, the ambient air oxygen partial pressure will be 159 mm Hg. During periods of high barometric pressure, the ambient oxygen partial pressure can reach 171 mm Hg; and during periods of low barometric pressure, the ambient partial pressure will reach 139 mm Hg. Related back to the standard barometric pressure of 760 mm Hg, this is a range of percent by volume of 18%-23%. Similarly, at an altitude of 4,000 feet, the ambient air oxygen partial pressure, for the standard barometric pressure at that altitude, will have fallen to 137 mm Hg which is equivalent to a sea level oxygen content of 18% by volume (4).

Navy studies of carbon dioxide toxicity reported by Schaefer (5) resulted in the following three levels to be used as tolerance limits:

1. 3 percent carbon dioxide as above: the level producing performance deterioration, alterations in basic physiological functions is expressed in changes of weight, blood pressure, pulse rate, metabolism and, finally pathological changes.

2. 1.5 percent carbon dioxide: the level at which basic performance and physiological functions are not affected. Under these conditions, however, slow adaptive processes are observed in electrolyte exchange and acid base balance regulations which might induce patho-physiological states on greatly prolonged exposure.

3. 0.5 - 0.8 percent carbon dioxide: the level at which probably no significant physiological, psychological or adaptive changes occur. The current British threshold limit value for carbon dioxide is 0.5 percent (6). The same value was also reported by Jennings (7) for use in the United States.

Ventilation Requirement for Minimum Oxygen Level

Using 18 percent as the minimum allowable concentration by volume for oxygen in a given space and assuming the activity level to be sedentary with an oxygen consumption of 0.80 cfh, the required ventilation rate of outside air containing 20.6 percent oxygen would be 0.51 cfm/person. A simplified equation used to determine this value is:

$$Q = \frac{P/60}{(C_{in} - C_{out})/100} \qquad (1)$$

where

Q = Ventilation rate, cfm/person

P = O_2 consumption, cfh/person

C_{in} = O_2 in ventilation air, percent

C_{out} = O_2 in room air, percent

Ventilation Rate to Maintain Maximum Carbon Dioxide Level

For a threshold limit value for carbon dioxide of 0.5 percent and with the ventilation air containing 0.03 percent carbon dioxide, the necessary ventilation rate can be determined from Equation 1 by replacing P with the carbon dioxide production in cfh/person and reversing the subscripts on the values of C. Therefore, the minimum ventilation rate to satisfy the carbon dioxide specifications for a sedentary occupant would be 2.38 cfm/person. From the two simple calculations above, it is apparent that the governing factor for the minimum ventilation rate is determined by that necessary to maintain the maximum level of carbon dioxide.

ASHRAE Ventilation Code Minimum Rate

The ASHRAE Standard, 1962-73, for natural and mechanical ventilation, specifies ventilation requirements for 100 percent outdoor air when the outdoor air meets certain specifications for air quality. The reduction in the amount of outside air is allowed when adequate temperature control is provided. Further reduction is permitted if high efficient absorption or other odor and gas removal equipment is employed. For the purpose of this report, however, the important specification is that in no case shall the outdoor air quantity be less than 5 cfm/person (8). It is interesting to note that in two proposed standards, the Australian proposed standard for mechanical ventilation and air-conditioning in buildings (draft dated November 1973) an equivalent recommendation is made: i.e., a minimum ventilation requirement of 5 cfm/person. The proposed ASHRAE standard 90 P, a standard for energy conservation in new buildings, currently has a requirement for a minimum ventilation of 5 cfm/person.

The recommended 5.0 cfm/person would appear to have a 100 percent safety factor in that the requirement for carbon dioxide dilution was found to be 2.38 cfm/person. In other words, the recommended value provides approximately 2.5 cfm/person for odor dilution. In the opinion of the ASHRAE Committee which formulated 62-73, if the space temperature is in the comfort zone so that no visible sweating occurs, and assuming no smoking or other source of contaminant generation, 2.5 cfm/person may be sufficient for odor control. This is based on personal experience and current practice recognizing the changes in hygiene and health which occurred over the past twenty to thirty years.

Natural Ventilation Through Open Windows

The natural forces available for moving air into, through and out of buildings are (a) wind forces; (b) forces due to stack effect; i.e., difference in temperature between the air inside and outside the building. Obviously it is very difficult to estimate the effect of wind since the wind velocity varies with time and direction. In addition, the local wind is effected by buildings, hills and other obstructions in the vicinity of the structure under consideration. In almost all localities, summer wind velocities are lower than those of the winter. In addition, the prevailing wind direction will be different during the summer and the winter.

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The flow of air through ventilation openings (windows) can be determined from Equation below:

$$Q = EAV \qquad (2)$$

where

Q = air flow, cfm

A = free area of openings, sf

V = wind velocity, fpm

E = effectiveness of openings

The effectiveness of an opening will vary with wind direction. Therefore, E should be taken as 0.5 - 0.6 for perpendicular winds; and 0.25 - 0.35 for diagonal winds. For flow due to a temperature difference between the room and the outside (stack effect):

$$Q = 9.4\, A\, h\, (t_i - t_o) \qquad (3)$$

where

Q = air flow, cf/m

A = free area of inlets, sf

h = height from inlets to outlets, ft

t_i = average temperature of indoor air at height, h, F

t_o = temperature of outdoor air, F

9.4 = constant of proportionality including a value of 65 percent for effectiveness of openings. This should be reduced to 50 percent; i.e., constant equal 7.2 if conditions are not favorable.

Both equations come from the ASHRAE Handbook of Fundamentals, Chapter 19 on Infiltration and Natural Ventilation, 1972.

Using Equation 2 and assuming that the open window area will be 5 percent of the floor area of a standard classroom of 750 sf, the volume of air entering the room when a perpendicular wind of five miles an hour impinges on the building will be 8,250 cfm. For 32 students in this classroom, the ventilation per student would be 257.8 cfm/person. Assuming a 9 ft ceiling, this would represent an air change rate of 73 air changes per hour.

In a recent study by A.G. Loudon at the Building Research Station in England, ventilation rates of 10 air changes per hour for schools with open windows on one side only were used to predict peak indoor temperatures.

In schools with windows on more than one side, air change rates were increased to 30 (9). Again, assuming the classroom is 750 sf x 9' high or a volume of 6750 cu ft, ten air changes per hour would represent an inflow of outside air of 67,500 cfh or 1,125 cfm. For 32 students in the classroom, this would represent a ventilation rate of 35 cfm/person.

The 1931 comprehensive study of School Ventilation by the New York Commission on Ventilation concluded that 10 to 15 cfm/person was an adequate fresh air requirement for schoolrooms and that this quantity could be obtained by "window gravity ventilation" (11).

Equations, similar to equations (1) and (2) based on the pressure difference created either by the wind pressure or the temperature difference, can be obtained from the IHVE Guide, Book B, 1972. Calculated ventilation flows, using the IHVE procedures for wind effect and stack effect for inlet and outlet openings of equal area, are given in Table 2 and 3. The table is based on an inlet and outlet area of 1.0 sf.

Table 2. Natural Ventilation Rate by Wind Effect
cfm/sq. meter (cfm/sf)

Bld. Ht. mtr	Bld. Ht. ft (Wind vel.)	Open Country mtr/sec. 9	mph 20.1	Suburban mtr/sec. 5.5	mph 12.3	City Center mtr/sec. 3.	mph 6.7
10	35.8	9,435	(877)	5,678	(527)	3,035	(282)
20	65.6	10,366	(963)	6,898	(641)	4,109	(382)

Table 3. Natural Ventilation Rate by Stack Effect
cfm/sq. meter (cfm/sf)

$t_i - t_o$ °C	°F (Bldg. Ht.)	meters 5.	ft 16.4	meters 10.	ft 32.8	meters 20.	ft 65.6
-10	-18	-1838	(-171)	-2569	(-239)	-3633	(-338)
0	0	0	(0)	0	(0)	0	(0)
10	18	1838	(171)	2569	(239)	3633	(338)
20	36	2569	(239)	3633	(338)	5108	(475)

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As indicated above, calculation of infiltration or ventilation through open windows requires several assumptions. For this reason, the "air change" method is often used. Values of 1.0 to 2.0 air changes per hour (ACPH) have been measured in residential buildings, classrooms and commercial buildings as normal leakage around windows, doors, etc. (12). Ventilation through open windows can produce air change rates of 10 to 30 per hour. Table 4 indicates the expected flow rate in a 750 sf classroom with a 9 ft ceiling.

Table 4. Range of Natural Ventilation Flow Rates

Air changes per hour	Flow Rate* cfm	Flow Rate/Student** cfm/person
1	112.5	3.5
2	225.0	7.0
5	562.5	17.6
10	1125.0	35.2
20	2250.0	70.3
30	3375.0	105.5

* Classroom 750 sf; 9 ft ceiling height
** 32 students

References for Nevins Study

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school lighting

1 ● SURVEY OF LIGHTING LITERATURE

Since the twenties, when serious attention was first given to light levels and related aspects of vision, the trend has been an ever-increasing illumination level in accordance with the assumed theory that more light is better. "More light increases the amount and the rate of information recovery," said one representative of the lighting industry in 1960, "and indoor lighting levels will rise with the standard of living until they are similar to outdoor levels." Comparisons between man's footcandle standards and light levels found in nature were given as follows:

30 fc (IES recommendations for school lighting in 1948)
70 fc (IES recommendations for school lighting in 1959)
350 fc (measured in shade of tree)
3,500 fc (average daylight year-round in NYC)

Though 3,500 footcandles have not been suggested for classroom lighting, the increase from 30-70 fc within an eleven year span is considerable.

Light Level Determination

The rationale for the latest increase is contained in a 1959 report published by the Illuminating Engineering Society based on a study conducted by H.R. Blackwell (Director, Vision Research Laboratories, University of Michigan, at time of research). Experiments conducted with a Visual Task Evaluator, an optical device designed to measure contrast values of simulated tasks, resulted in values of illumination in footcandles. It is assumed that 99 percent accuracy is required for carrying out visual tasks ranging from reading a poor quality reproduction to a sample of good ink writing. According to the IES Lighting Handbook (5th Edition, based on the Blackwell findings) the greater part of a student's visual time application is spent on tasks requiring 70-100 fc Equivalent Sphere Illumination (writing with pencil, reading, working with duplicated material). It is then concluded that the general light level should be designed for the most difficult commonly

found tasks. While perfect general illumination uniformity is usually unfeasible, the IES Handbook contends that uniformity is acceptable if the maximum and minimum values in the work-space of the room are not more that 1/6 above or below average.

The outcome of this approach to lighting design is a uniformly high light level which will provide for accomplishment of the most demanding task at any location within the space.

"The effect of new light levels" was the main topic of the 1959 conference of the Building Research Institute in which Fisher S. Black said in his keynote speech "A new revolution has come to the lighting industry. It all started with the release last year of the Blackwell report. The IES then took the lighting levels recommended by Blackwell and applied them to hundreds of seeing tasks and came up with new lighting levels ... too much light? ... we cannot have too much light."

In an article (Jan/Feb '69) entitled "Why more footcandles are being recommended for schools," the editors of Better Light, Better Sight News suggested that "The technical societies that make recommendations -- notably the Illuminating Engineering Society -- have recognized the engineering obligation of balancing visual goals with economic and scientific practicality. Recommendations must bear some relation to our capabilities for achieving them. And only recently could we obtain -- and actually afford to obtain -- the 50-500 fc which many experts feel covers the ideal range for working vision under the conditions of modern civilization."

British Illumination Levels

In contrast is the British attitude towards lighting as expressed in the official government Bulletin No. 33 on 'Lighting in Schools.' Britain also uses the recommendations of its Illuminating Engineering Society for maintaining illumination levels in schools and colleges. However, it is stated in the bulletin,

> "these are not the Department's official recommendations and the actual quantity of lighting provided will have to be decided after consideration of the likely capital cost of the electrical installation (and of the charges for current), bearing in mind the principle that it is desirable that the money available for a school should be distributed in a balanced fashion over the various elements in the building. It may well be necessary to choose a level of lighting which falls between the IES Code figures and the Regulation minimum of 10 lm/sf... To ensure that none of the working areas in the room fall beneath this, it is necessary to design for a higher average level of illumination. The reason why this level was chosen as the minimum was that research work had shown that at least

> four-fifths of school children achieved a good standard of vision at 10 lm/sf and could see well enough to do normal school work such as reading 3/4" high writing on a chalkboard at a distance of 30 ft. Below this level of illumination visual acuity fell away rapidly. Above 10 lm/sf it was found that visual performance did not improve proportionately with increases in the level of illumination."

The bulletin further suggests that instead of light level increases,

> "Visual tasks can be made easier by an increase in contrast or size of details... Thus for the teacher to write on the chalkboard with letters 1½" high instead of 1" high would be as effective in improving visibility as would raising the level of illumination by ten times... For a child to move 4 ft closer to the chalkboard will have visual advantages for him which can only be matched by raising the level of illumination by 30 times. Higher levels of illumination will be needed for specialized classrooms but regulations deal only in general terms and leave engineers and architects to use their own judgement."

U.S. Lighting Experiments

Similar conclusions for illumination levels in schools were reached by several U.S. educators whose experiments were published in 1965 in the book 'Bases for Effective Reading". In it the author Miles A. Tinker reviews his own research and that of others conducted over the past 25 years. Concerning light level requirements for reading, he states:

Visual Acuity and Light Intensity

> "Data on the relation of visual acuity to intensity of light reveal the following trends: visual acuity increases rapidly as light intensity is increased from a fraction of a fc to 5 fc and then gradually in acuity up to between 25-40 fc. As the illumination intensity is further increased up to 100 fc or even above 1,000 fc, the improvements in acuity are slight. Although the gains in acuity with intensities above 50 fc may have theoretical implications, they have no practical significance for reading. To argue from these data that high intensities are best for ordinary reading is not valid. Size of the object to be discriminated is a factor in seeing. Relation between light intensity and speed of vision is logarithmic. Plotted curves are deceptive (minute gains for the higher intensities look big) and should not be employed to specify illumination for reading. Visual acuity measurements have been used widely as a basis for prescribing illumination for reading. Luckiesh, and Luckiesh & Moss list visual acuity as a basic factor in

Light Intensity and Speed of Vision

> seeing and by implication in specific visual tasks such as reading. They state that, for black test objects on a white background, visual acuity improves up to 100 fc. As a matter of fact, Lythgoe has demonstrated that under certain conditions of measurement visual acuity improves up to and beyond 1,000 fc. But inspection of his data reveals that gains in acuity, when illumination intensity is doubled, are very slight for levels above about 20 fc. It is questionable whether the almost microscopic gains in visual acuity obtained under the relatively high fc of light justify their application to visual tasks such as reading where suprathreshold visibility is involved. Visual acuity measurements yield threshold values of seeing. Evaluation of all the data on increase of visual acuity with increase of light intensity indicates that they have little value as a basis for prescribing illumination for reading."

According to experiments by Lythgoe, visual acuity continued to improve to 1,275 fL but the increase in acuity by doubling the brightness was extremely small beyond 38.8 fL.

Unlike Blackwell, Tinker sees the reading task in terms of continuous visual patterns, composed of words and sentences, rather than individual letters. The implication for school lighting levels is that reading is not one of the activities that is performed at the threshold of visual capability. It does not require the precision that would be needed to read a vernier on a surveyor's transit, for example. As a result, tests to determine accuracy of perception under threshold conditions do not establish significant data for less demanding visual tasks.

Effect of Adaptation Upon Visual Efficiency

Tinker places particular emphasis on the effect of adaptation upon visual efficiency. First, the aperture of the iris contracts or expands to regulate the amount of light entering the eye. Secondly, the retina adjusts its sensitivity to changes in levels of brightness of the light falling upon its surface. "The normal eye," he says, "has a remarkable ability to adapt for clear vision to a wide range of light intensities from relatively dim to very bright. Research indicates that this function resides in the retina. ...It takes 7 to 8 minutes for the cones to adapt to dim light, and 60 to 90 seconds to adapt to bright light. The effect of adaptation upon visual efficiency is illustrated in an experiment by Tinker. He determined speed of reading under various intensities of light with 2 minutes of adaptation to each illumination used and also with 15 minutes of adaptation to the light levels. The illumination intensities employed were 0.1, 0.7, 3.1, 10.3, 17.4 and 53.3 fc. With only 2 minutes of adaptation, light intensities below 10.3 fc significantly retarded speed of reading. The rate of reading was the same for 10.3, 17.4 and 53.3 fc. In con-

trast, with 15 minutes of adaptation, only the light intensities below 3.1 fc significantly retarded speed of reading, while the reading rate was the same for 3.1 fc and above. Thus, with ample time for adaptation (15 minutes) the speed and accuracy of vision in reading was as good at 3.1 fc as at the brighter levels of illumination. Adequate adaptation to the dimmer light produced greater visual efficiency than when no adaptation was provided for."

Various attempts have been made to arrive at light levels by reader preference. "In all studies reported," says Tinker, "the authors neglected the role of visual adaptation. This led to erroneous specification of high intensities for reading. In an intensive investigation with 144 university students as subjects, Tinker determined the effect of visual adaptation upon intensity of diffused light preferred for reading. At one lab session, subjects adapted 15 minutes to 8 fc, at another to 52 fc. When adapted to 8 fc, subjects tended to choose 8 fc as most comfortable; when adapted to 52 fc, they chose 52 fc most often... Apparently, by picking an intensity and adapting the reader to it, one can obtain preference for that intensity. If the investigator is interested in promoting use of lights of high intensity, the method of preferences will support it."

According to Tinker, the following light intensities should be adequate for reading:

For sustained reading of books and magazines (10-12 pt. type)	15 - 25 fc
For sustained reading of small print (7-8 pt. type)	25 - 35 fc
In ordinary schoolrooms	20 - 30 fc
For mechanical drawing	±40 fc
For casual (short) periods of reading good book-size print	10 - 15 fc
For smaller print	15 - 20 fc
When brightness contrast between print and paper is 40-55	35 - 50 fc
When brightness contrast is very low 20-30 (seldom found in practical reading situations)	75 - 100 fc
Few reading situations in homes, schools, offices, libraries require more than 50 fc	
For eyes with less than normal visual acuity (casual reading)	25 - 30 fc
For eyes with less than normal visual acuity (sustained reading)	40 - 50 fc
Sight-saving classes	50 - 60 fc

The experiments of Kunz and Sleight also reported in 'Bases for Effective Reading', suggest that adequate illumination for discriminating details range between:

12.5 - 38 fc for normal vision

38 - 50 fc for sub-normal vision

for reading ordinary bookprint:

15 - 25 fc for normal vision
35 - 40 fc for sub-normal vision

The need for variety in lighting was pointed out in an article by R.C. Aldworth and D.J. Bridgers in Lighting Research and Technology (Vol. 3, No. 1, 1971) " In many working areas, monotonous surroundings may well seriously affect working efficiency... When the retina is stimulated by light, the signals are transmitted to the visual center in the cortex and simultaneously to the reticular formation. which begins to work on the whole brain, raising the person's awareness. At the same time signals received by the other senses, such as hearing and touch, also excite the reticular formation, and therefore visual performance can be affected by stimulation of apparently unconnected sensory stimuli."

Lighting and Ocular Health

Literature on the subject of lighting in relation to ocular health is surprisingly limited and often contradictory. According to the tests of Ferree, Rand & Lewis and Luckiesh & Moss, eye strain with resulting functional disturbance of other organs is held to be directly traceable at times to faulty illumination. However, ophtalmologists indicate that on the whole there is no evidence of any relationship between general illumination levels and eye health.

Britain's Research Station concludes that no evidence has been found that myopia is caused by poor lighting, nor that the onset of juvenile visual defects has in any way been affected by the higher light levels of today.

In 'System of Ophtalmology', Sir Stewart Duke-Elder suggests that eyestrain can be reduced and visual efficiency increased most effectively by increasing the apparent size of the objects comprising the visual task. According to the experiments of Weston, a ten-fold increase in illumination produced an improvement of 30 percent in the performance of a simple visual task, whereas increasing the apparent size ten times produced a 200 percent improvement in performance.

Day Lighting of Schools

"Windows are openings to the outside world in more ways than one," says James Marston Fitch in his book, 'American Building: The Environmental Forces that Shape it'. "When the desk worker or the student looks out of the window instead of down at his work, he is not wasting time; he is seeking psychic as well as optical relief from a highly structured and unnaturally monochromatic experience." This factor has been largely ignored in recent attempts to make the school environment completely windowless... "Only the viewing function still continues to keep windows from becoming wholly obsolete technologically," concluded C. Theodore Larson of the Architectural Research Laboratory, at

the University of Michigan, in his report on "The Effect of Windowless Classrooms on Elementary School Children". In it he states that, "The ventilating function has been taken over by the development of mechanical systems that can condition the air in any classroom to any desired degree of freshness and warmth or coolness and to any desired rate of movement. The emphasis on day-lighting has likewise been shifted over into new technologies of artifical illumination. . . If outside view is unpleasant or potentially disturbing, there seems little point in having any windows at all." The opposite point of view is presented in Bulletin No. 33, the British government publication: "Large windows, it is said, can lead to overheating on sunny days in summer; conversely, they cause excessive heat losses on cold days in winter. Windows tend to be more expensive than solid walls. It is pointed out that daylight is not in fact free but has to be paid for in cost of lengthy perimeters and elaborate sectional devices which are necessary to secure its entry to the building. Moreover, window blinds have often to be added, and window cleaning is an expensive form of maintenance. . . Why not leave out windows? Some schools in the USA are windowless with a constant artificial indoor climate -- so why not here? It is also argued that high levels of illumination are now necessary and that daylighting could not provide these satisfactorily . . . Nevertheless, daylight, when properly designed, is still the most satisfactory and economic method of providing working illumination, and it makes a contribution to the educational and visual environment of a school, which cannot be made in any other way . . . desire to keep in touch with the world outside . . . with constant shift in weather, seasons."
Daylight cannot be simulated by artificial light. It is variable in quantity, color, has different spectral composition from any artificial light and appears to be one of life's necessities and pleasures. It is not uncommon, for example, in Sweden, Finland and Russia that daylight deprivation will cause psychosomatic upsets.

Bulletin No. 33 provides guidelines on the amount of daylight required for sufficient illumination within the school: "Any method of lighting design using daylight as the main source of illumination must make sure that there is sufficient lighting in the building on all but the dullest days, and must take into account the hours during which the school is occupied...A sky providing 500 Lm/sf should be taken as the lowest level that a designer would be expected to cope with...Artificial lighting will be needed to supplement daylight at the back of a room. This is likely to be necessary for about 200 hours per annum over the part of a schoolroom designed to a 2 percent minimum daylight factor, for example, a sky which gives illumination of 500 Lm/sf outside will provide an illumination of 2/100 x 500 = 10 Lm/sf. Where difficult tasks are performed, use higher than 2 percent but avoid sky glare, solar heat gain and loss. Consider possibility of top lighting."

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School Lighting

Too little attention has been paid in the USA to the integration of daylight and artificial illumination. As James Marston Fitch has commented on this topic and on the state of the art in general: "Historically, illuminating engineering was developed primarily to expedite process, and only indirectly eye health or well-being; today it bears the characteristic imprint of this history. Its development has been uneven, with enormous qualitative discrepancies between the highest and lowest examples, with instances of gross deficiencies side by side with extravagant waste. This paradox is very clear in our mechanical separation of problems of artifical illumination and daylighting when, in most building types, they could be thoroughly integrated to benefit both."

h-2

school lighting

2 ● COMPARATIVE LISTING OF LIGHTING STANDARDS

Light level specifications for schools vary widely as indicated by the following survey of lighting standards recommended by various government agencies, school authorities, and industry spokesmen. For purposes of comparison British government and industry standards are also listed.

FIGURE h-2/1:
COMPARATIVE LISTING
OF LIGHT LEVELS

	NY STATE EDUC. DEPT. MIN. REQ. FOR PUBLIC SCHOOLS 1973[1]	NYC B'D OF ED. MANUAL OF SCHOOL PLANNING 1971	IES (USA) LIGHTING HANDBOOK 1972	IES (BRITAIN) LIGHTING CODE 1961	BRITISH STAND'S FOR SCHOOL PREMISES REGULATIONS 1959	DEPT. OF WATER, SEWER, GAS & ELECTRICITY 1971	NYC BUILDING CODE 1968	AMERICAN SOC. OF HEATING REF. & A/C ENGINEERS 1955[13]	NYC HEALTH CODE 1959/1964
Art Rooms			70 FC	45LM/SF[4]					
Audio-Visual Spaces			30-100 FC						
Auditorium	10 FC	30-60 FC		15-30LM/SF[5]	10 LM/SF[6]	30 FC		10 FC	
Assembly		30-60 FC	15 FC	15LM/SF		30 FC	5 FC[7]		
Stage/Exhibition		30-60 FC	30 FC	30LM/SF			½FC[8]		10 FC
Social Activities		30 FC	5 FC						
Cafeteria	20 FC	30-60 FC	10-100 FC			30 FC		10 FC	10 FC
Classrooms	30 FC	60 FC[2]			10 LM/SF[6]	60 FC		30 FC[11]	
General Use		60 FC[2]	70 FC	30LM/SF	10 LM/SF[6]	60 FC		30 FC[11]	30 FC
Demonstration Area			150 FC	20-30LM/SF				30-300 FC[12]	
Study Halls	30 FC		70 ESI[3]						30 FC
Gymnasium	20 FC	30 FC			10 LM/SF[6]	30 FC			
General Exercises		30 FC	30 FC					20 FC	
Exhibition/Matches		30 FC	50 FC						
Assemblies		30 FC	10 FC						
Laboratories			100 FC	30LM/SF				30 FC	
Lecture Rooms					10 LM/SF[6]				
Audience Areas			70 ESI[3]	30LM/SF					
Demonstration Area			150 FC	20-30LM/SF					

(1) Conference on Energy Usage Nov. '73. (2) 75 FC for children with limited vision. (3) ESI (Equivalent Sphere Illumination) takes into account footcandle measurements and level of task illumination and brightness, veiling reflections and effect of disability glare and transient adaptation. (4) Lumen/SQ FT (LM/SF) amount of light generated by a luminous source (1 LM/SF = 1 FC). (5) 30 LM/SF when used for examinations. (6) Min. requirement plus 2% daylight factor for all teaching accommodations. (7) At floor level. (8) For aisles and cross aisles. (9) At 30" above floor. (10) At floor for egress. (11) On desk. (12) On chalkboard. (13) From "A Study of the Thermal Aspects of the Lighting system."

FIGURE h-2/2:
COMPARATIVE LISTING
OF LIGHT LEVELS

	NY STATE EDUC. DEPT. MIN. REQ. FOR PUBLIC SCHOOLS(1) 1973	NYC B'D OF ED. MANUAL OF SCHOOL PLANNING 1971	IES (USA) LIGHTING HANDBOOK 1972	IES (BRITAIN) LIGHTING CODE 1961	BRITISH STAND'S FOR SCHOOL PREMISES REGULATIONS 1959	DEPT. OF WATER, SEWER, GAS & ELECTRICITY 1971	NYC BUILDING CODE 1968	AMERICAN SOC. OF HEATING REF. & A/C ENGINEERS(13) 1955	NYC HEALTH CODE 1959/1964
Libraries	30 FC				10 LM/SF(6)				
Reading Areas		60 FC	30-70 ESI(3)	30LM/SF		70 FC		30 FC	30 FC
Study Carrel			70 ESI(3)						
Book Stacks			5-30 FC	5-10LM/SF		20 FC			
Music Rooms			30-70 ESI(3)		10 LM/SF(6)	60-75 FC			
Offices	30 FC	60 FC	70-150 ESI(3)	30LM/SF					
Services									
Store Rooms			5-50 FC					5 FC	5 FC
Toilets/Washrooms	10 FC	20 FC	30 FC				10 FC(9)	10 FC	10 FC
Corridors/Stairways	10 FC	10-20 FC	20 FC	7-10LM/SF		20 FC	5 FC(10)	10 FC	10 FC
Locker Rooms	10 FC	20-30 FC	20 FC			20 FC		10 FC	10 FC
Staff Room/Common Rooms				15LM/SF					20 FC
Vocational Education									
Shops	30 FC	60 FC	100 FC			75 FC		30 FC	
Drafting	40 FC		100 ESI(3)			100 FC		50 FC	50 FC
Typing			70 ESI(3)						50 FC
Sewing	40 FC		150 FC	70LM/SF					50 FC
Cooking			50 FC						

(1) Conference on Energy Usage Nov. '73. (2) 75 FC for children with limited vision. (3) ESI (Equivalent Sphere Illumination) takes into account footcandle measurements and level of task illumination and brightness, veiling reflections and effect of disability glare and transient adaptation. (4) Lumen/SQ FT (LM/SF) amount of light generated by a luminous source (1 LM/SF = 1 FC). (5) 30 LM/SF when used for examinations. (6) Min. requirement plus 2% daylight factor for all teaching accommodations. (7) At floor level. (8) For aisles and cross aisles. (9) At 30" above floor. (10) At floor for egress. (11) On desk. (12) On chalkboard. (13) From "A Study of the Thermal Aspects of the Lighting system."

h-3

school lighting

3 ● EFFECTS OF LIGHT LEVELS ON READING SCORES

The New York City Board of Education issues reading tests to all of its students each year. These are the only completely standardized exams given throughout the system. An attempt was made to determine whether there was any clear relationship between lighting levels and these scores. In order to do this, four schools were selected which were modernized in 1970. The four schools were built in 1924, 1899, 1909 and 1925. Each of these schools was paired with the closest similar type (PS, IS) school in the same district. These schools were built in 1954, 1952, 1926 and 1930. The last two schools were modernized in 1967 and 1965 respectively. These pairs of schools will be referred to as A, B, C and D. The schools which underwent changes during the six-year period will be referred to as altered schools, the others as unchanged. The typical classrooms in the altered schools are about 600 sf and were originally illuminated by five 200 w incandescent fixtures with opal glass covers, yielding a light level of 5-7 fc. As part of the alterations, the incandescent systems were replaced with fluorescents which were installed to a design criteria of 60 fc. The unchanged schools were all provided with fluorescent systems before the six-year period under study.

The two schools being compared in each case were selected for being as similar as possible in order to minimize the effect of varying external factors on the scores. Since this cannot be totally achieved, the patterns which will be discussed are not absolute levels but changes in differentials. In each case, the unchanged (control) school is as similar as possible to the school being altered with the exception of having constant design light levels during the six-year period.

Each point which is plotted represents the mean score for one class in one school. This may range from about 100 to over 300 individual scores. Therefore, each change in differential which is described by 4 points is based on a

minimum of four hundred reading scores.

In general, the pattern of reading score differentials is highly erratic. There are two aspects, however, which appear to be related to the alteration program. First, immediately after the alteration, 12 out of 18 of the altered schools improved with respect to the corresponding unchanged schools, four remained equal and two declined. This indicates a short term boost in student performance (figure h-3/11). In the second year after the alteration, the erratic pattern of relative performance returns. Two years later, the trend was reversed and 12 of the 18 classes from unchanged schools showed improvements relative to those from the altered schools. Further, over a six-year period, nine of the eighteen classes in altered schools improved their positions over corresponding classes in unchanged schools and nine declined. At the beginning of the study period, the average of scores from the schools to be altered was .29 of a grade level higher than those which would remain unchanged. At the end of the study period, it was .11 higher, indicating that the increase in light levels during the study period did not have a lasting effect on the reading performance.

The following generalizations can be made regarding the data presented in figures h-3/1 to h-3/11:

1. During the six-year period, the average of reading scores of all schools observed declined.

2. The overall decline of the altered schools was greater than that of the unchanged schools although only slightly.

3. The altered schools showed the best relative performance in the year immediately after their renovation.

On the basis of more than 30,000 individual reading scores, it is not possible to demonstrate that increased light levels affect educational performance beyond the so-called "Hawthorne Effect."

It is generally acknowledged that reading scores offer only a limited indication of a child's learning capacity. However, since the reading/comprehension tests given by the New York City Board of Education are the only city-wide standardized tests given, the test results do provide some measure of comparison.

h-3/3
School
Lighting

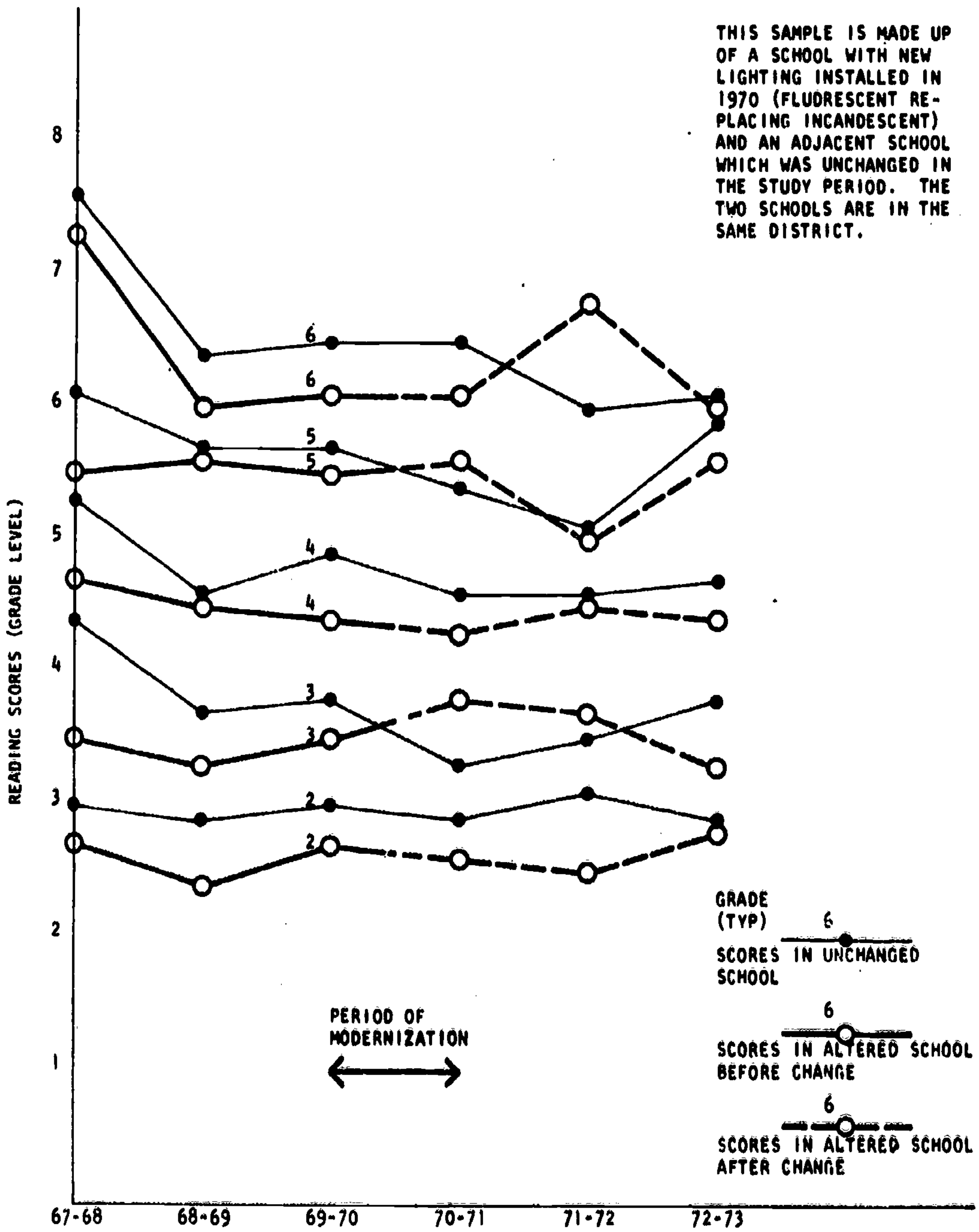

FIGURE h-3/1:
READING SCORES
PAIR A

ROS 6 A -74

THESE GPAPHS INDICATE THE READING SCORE DIFFERENTIALS BETWEEN THE GRAOES IN THE ALTERED SCHOOL (—O—) AND THE UNCHANGED SCHOOL (—●—) ON TABLE 1-a. A POSITIVE DIFFERENTIAL INOICATES A HIGHER SCORE FOR THE ALTERED SCHOOL.

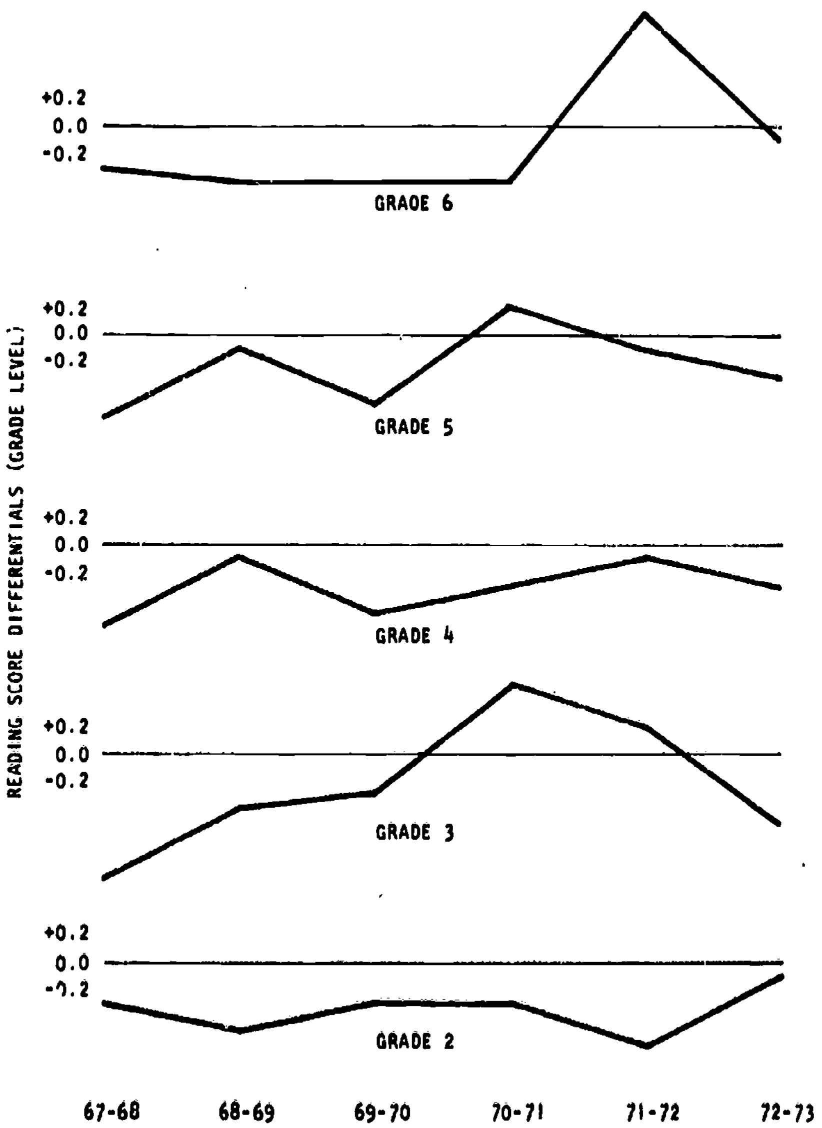

FIGURE h-3/2:
READING SCORE
DIFFERENTIALS
PAIR A

RGS & A - 74.

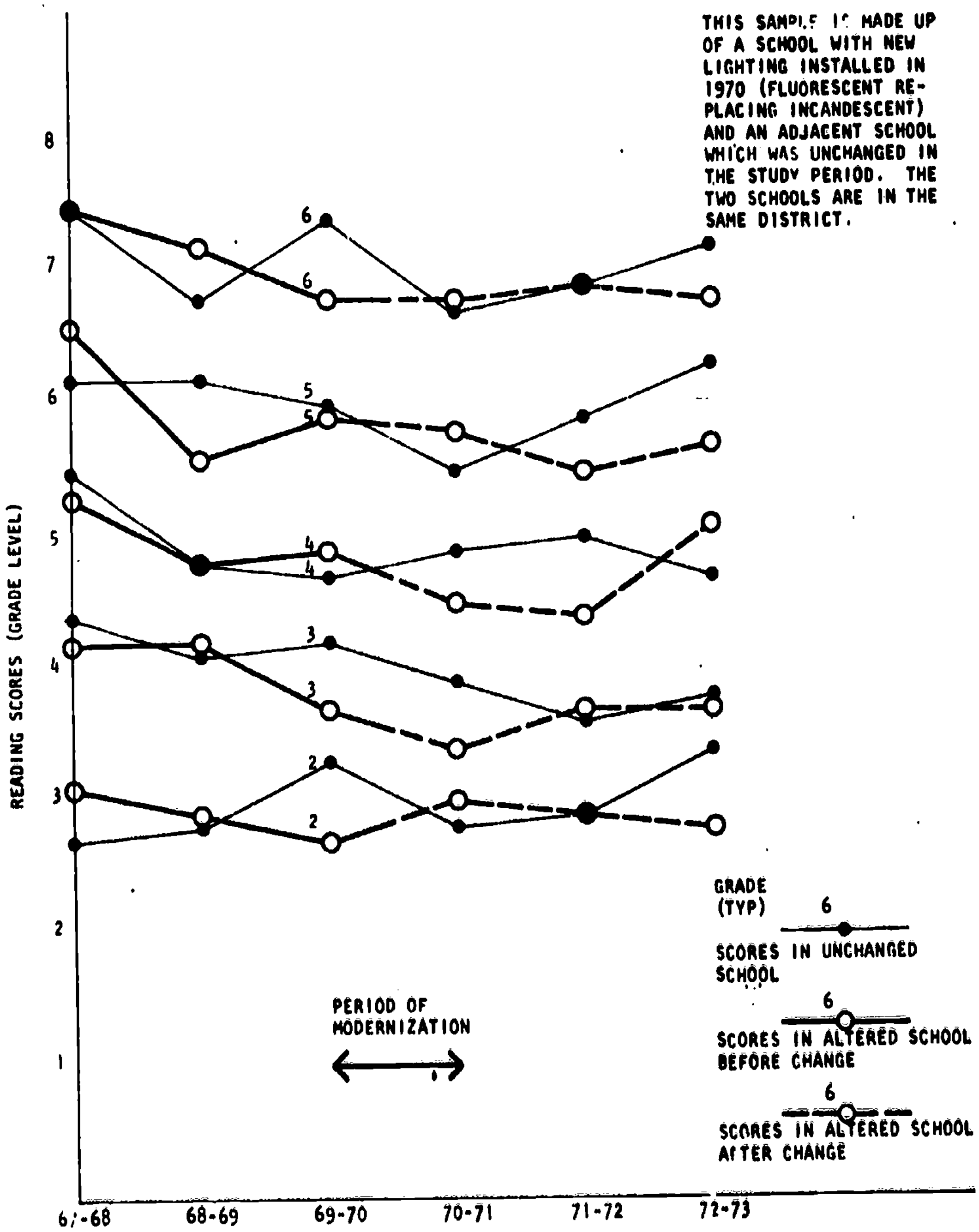

FIGURE h-3/3:
READING SCORES
PAIR B

RGS & A - 74

THESE GRAPHS INDICATE THE READING SCORE DIFFERENTIALS BETWEEN THE GRADES IN THE ALTERED SCHOOL (—○—) AND THE UNCHANGED SCHOOL (—●—) ON TABLE 2-a. A POSITIVE DIFFERENTIAL INDICATES A HIGHER SCORE FOR THE ALTERED SCHOOL.

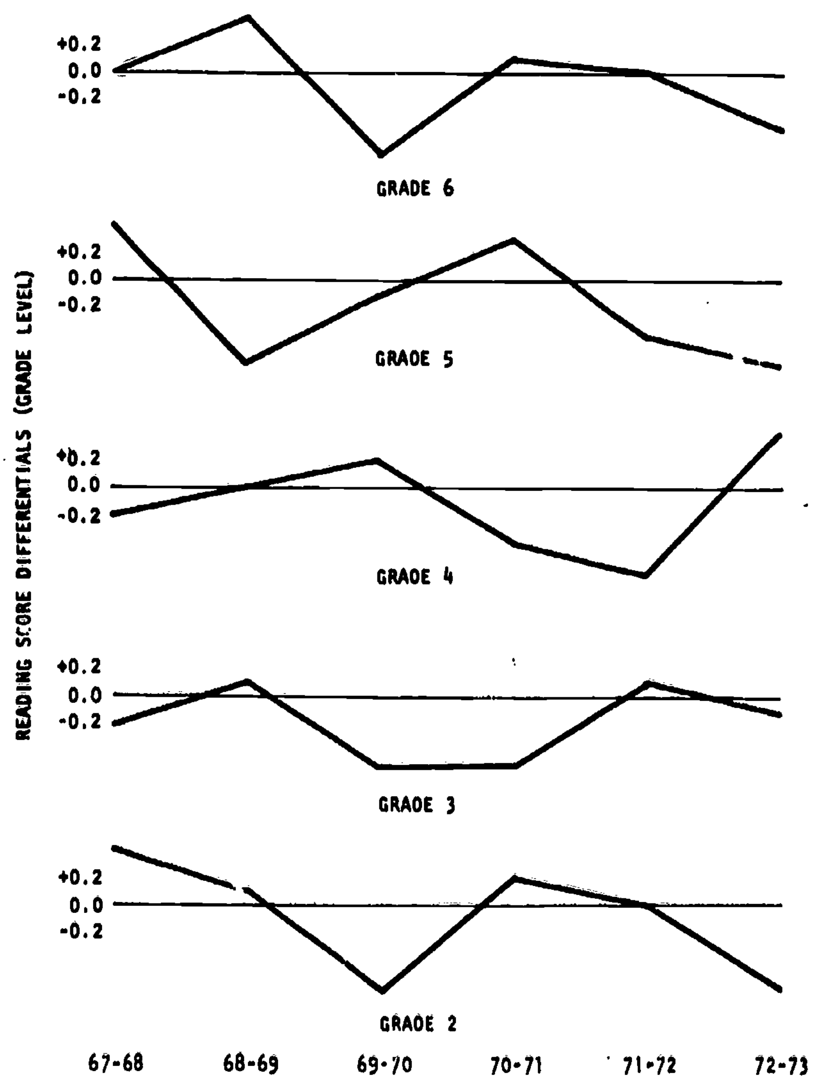

FIGURE h-3/4:
READING SCORE
DIFFERENTIALS
PAIR B

NOTE: BECAUSE OF THE RANGE OF THE SCORES IN THIS PAIR OF SCHOOLS, THE DATA IS PRESENTED ON 2 TABLES (C-1 AND C-2)

TABLE 3-a
C-1

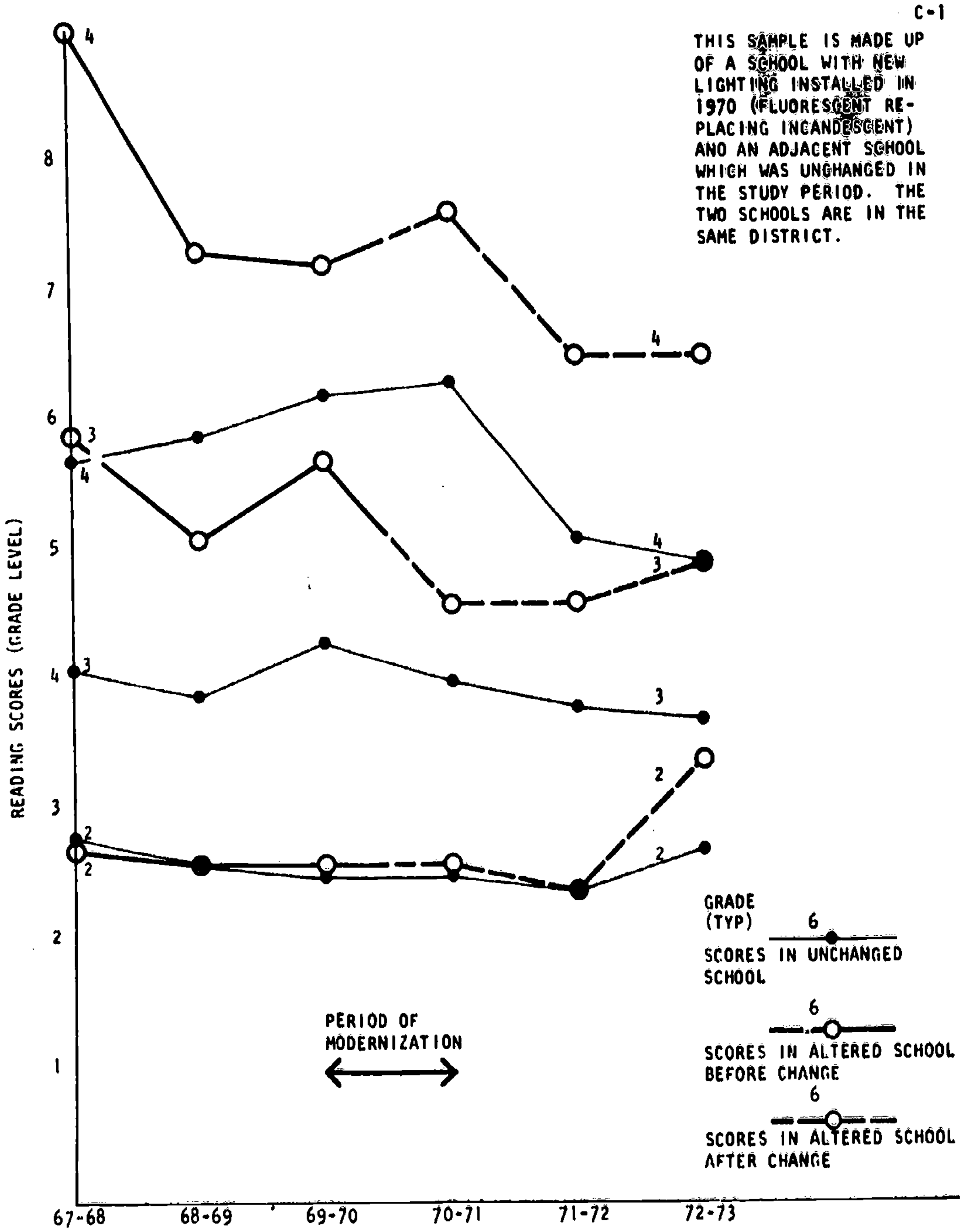

FIGURE h-3/5:
READING SCORES
PAIR C-1

TABLE 3-b
C-1

THESE GRAPHS INDICATE THE READING SCORE DIFFERENTIALS BETWEEN THE GRADES IN THE ALTERED SCHOOL (—○—) AND THE UNCHANGED SCHOOL (—●—) ON TABLE 3-a. A POSITIVE DIFFERENTIAL INDICATES A HIGHER SCORE FOR THE ALTERED SCHOOL.

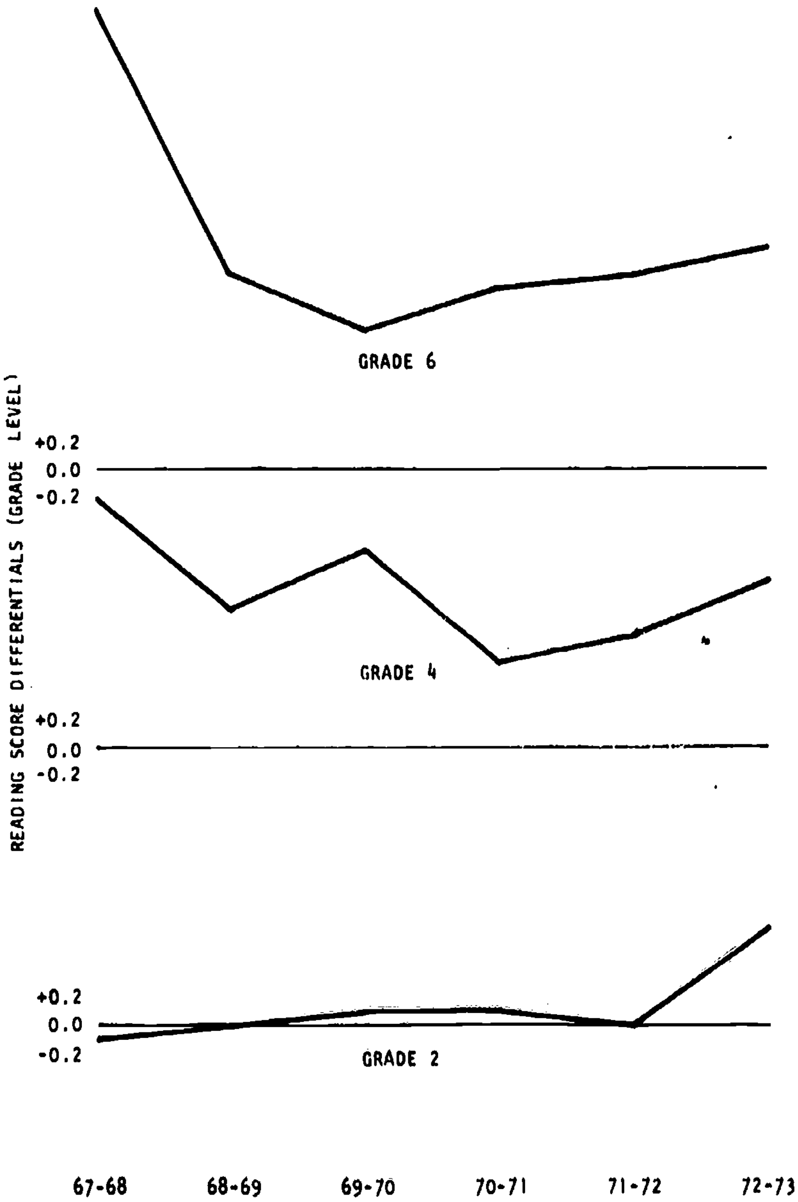

FIGURE h-3/6:
READING SCORE
DIFFERENTIALS
PAIR C-1

RGS & A - 74

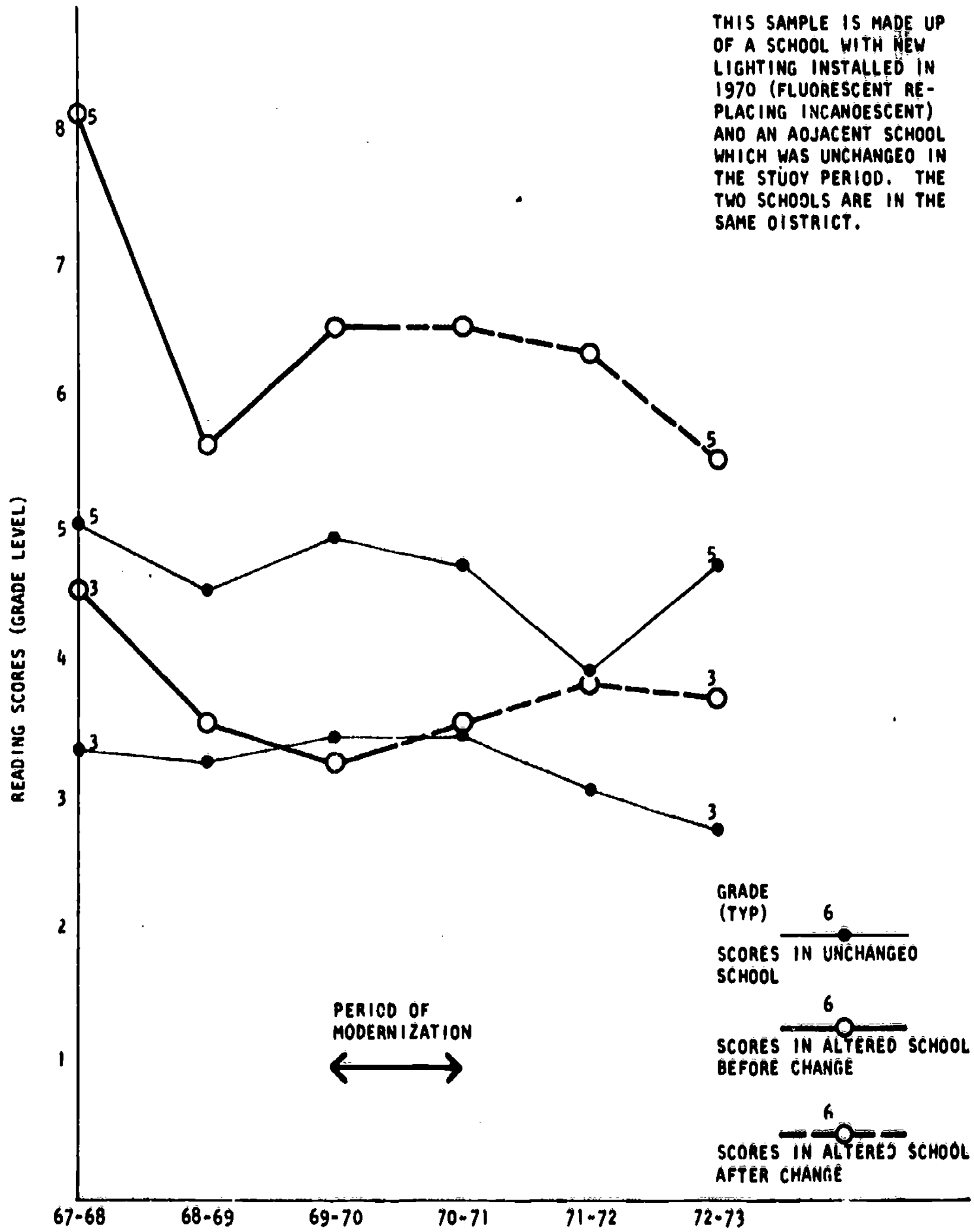

FIGURE h-3/7:
READING SCORES
PAIR C-2

THESE GRAPHS INDICATE THE READING SCORE DIFFERENTIALS BETWEEN THE GRADES IN THE ALTERED SCHOOL (—O—) AND THE UNCHANGED SCHOOL (—●—) ON TABLE 4-a. A POSITIVE DIFFERENTIAL INDICATES A HIGHER SCORE FOR THE ALTERED SCHOOL.

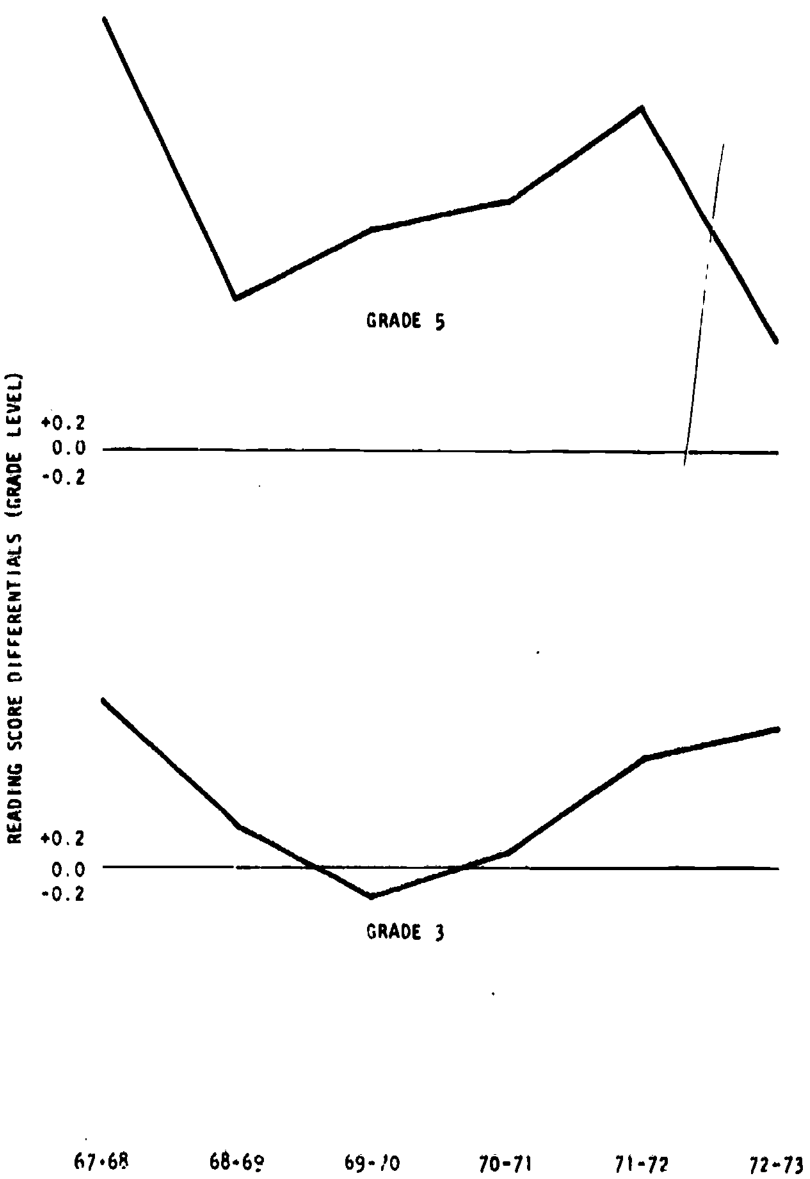

FIGURE h-3/8:
READING SCORE
DIFFERENTIALS
PAIR C-2

RGS & A - 74

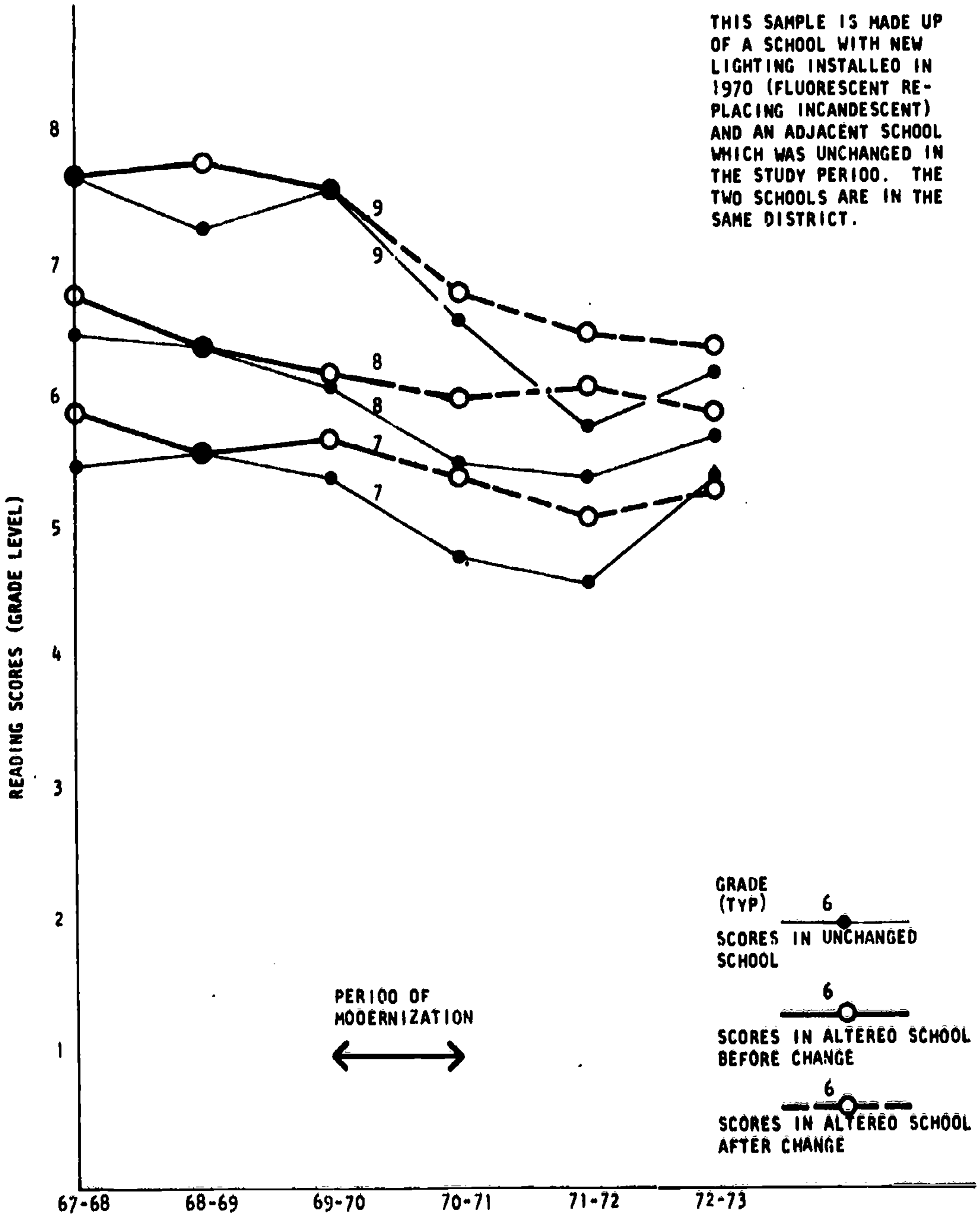

FIGURE h-3/9:
READING SCORES
PAIR D

RGS & A - 74

THESE GRAPHS INDICATE THE READING SCORE DIFFERENTIALS BETWEEN THE GRADES IN THE ALTERED SCHOOL (—O—) AND THE UNCHANGED SCHOOL (—●—) ON TABLE 5-a. A POSITIVE DIFFERENTIAL INDICATES A HIGHER SCORE FOR THE ALTERED SCHOOL.

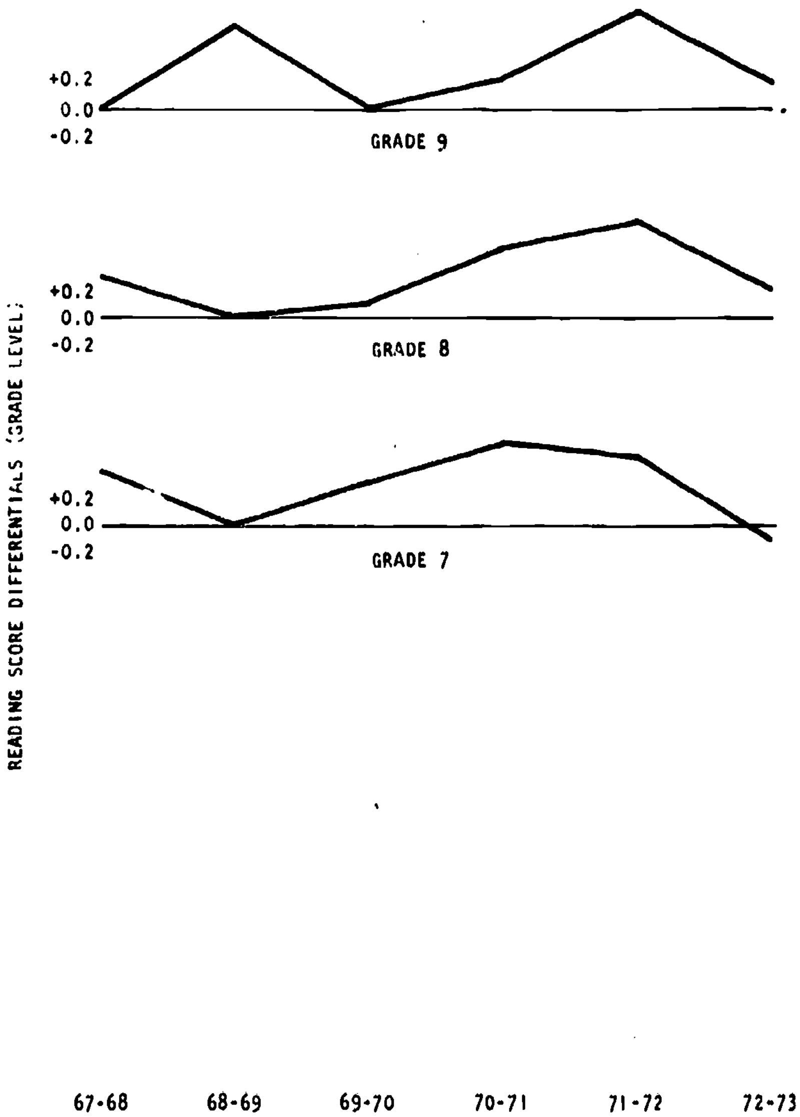

FIGURE h-3/10:
READING SCORE
DIFFERENTIALS
PAIR D

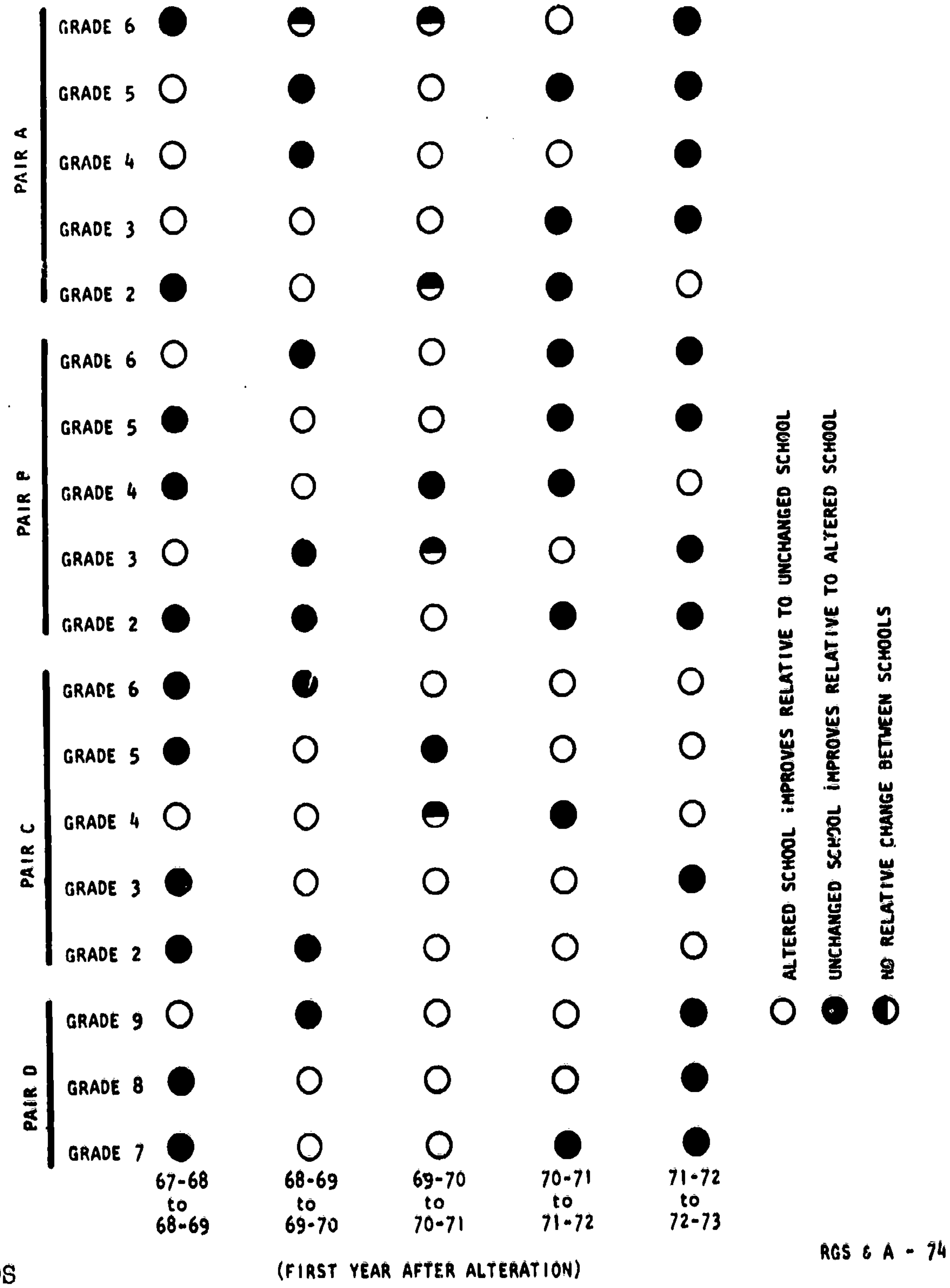

FIGURE h-3/11:
READING SCORE
DIFFERENTIAL TRENDS

i

educational tasks and environmental conditions

It is the purpose of this study to determine how the physical school environment can best serve the pedagogic demands. Toward this end an investigation of educational activities was conducted by a team of observers - architects and members of the New York Board of Education - who recorded all of the possible learning/teaching activities, and listed concurrently 1. the type of student grouping (students working singly, in small groups, in standard class sizes or larger); 2. the presence of teachers, para-professionals or other personnel; 3. the types of teaching aids or special equipment; 4. the space designation (classroom, art room, shops and specialized teaching spaces, auditorium, cafeteria, corridor, library, gymnasium, staff offices) and 5. the actual student station (desk, carrel, station at equipment, etc.). In breaking all of the educational activities into their component parts, it became possible to be much more specific in assigning values to the "Desirable Environmental Conditions". In the area of lighting, for example, this itemized system has made it possible to assign light intensities to each specific task. In contrast to the currently prescribed uniformly high light levels (60 FC to 70 FC in classrooms, based on the light requirements of the most exacting task within each space), the alternative method will make use of a lower overall light level, supplemented by light sources focused directly onto specific educational tasks. This method offers several advantages: First, it avoids fixed illumination levels which tend to be monotonous and fatiguing. Second, the brightest light levels will be concentrated on the teaching/learning areas where the attention of the student will automatically be focused. Third, since 60% of the electric consumption in a school goes into lighting, one-third to one-half of this amount of energy can be reduced by this method.

In step two, values have been assigned to the "Desirable Environmental Conditions" on the basis of findings derived from the following special studies:

Sub-report f: Fuel and Electricity Use in NYC Schools

Sub-report f-4: System Analysis of Selected Sample

Sub-report f-5: Preliminary Analysis of Emergency Energy-Saving Measures Initiated by the New York City Board of Education 1973 - 1974

Sub-report g-1: Observed Light Levels in 20 Classrooms

Sub-report g-2: Analysis of Observed Ventilation Performance

Sub-report h-2: School Lighting Standards

Sub-report h-3: Light Level Changes and their Effects on Reading and Comprehension Scores

Note: "Desirable Environmental Conditions" listed in the following charts are based on:

SQ. FT. AREA PER STUDENT: Standards of New York City Building Code, 1968

TEMPERATURE (For heating purposes): $68^{\circ}F$ for all sedentary activities; $65^{\circ}F$ for active occupations

VENTILATION LEVEL: Findings of special study (Sub-report g-2)

L = Low (5 cfm per occupant)
H = High (10 - 15 cfm per occupant)
I = Intermittent (non-continuous operation)

AMBIENT LIGHT LEVEL: Findings of special studies (sub-reports g-1, h-2, h-3)

Ambient Light Level 1 = Artificial illumination to provide sufficient light for general safety, and ambient light for audio-visual presentations and non-visual tasks (5-15 FC)

Ambient Light Level 2 = Artificial illumination for general use, for reading and writing, supplemented by task lighting where necessary (15-30 FC)

Ambient Light Level 3 = Artificial illumination for more precise tasks such as reading fine print, painting, model making, sewing, drafting (30-50 FC).

TASK LIGHT: Findings of special studies (sub-reports g-1, h-1, h-2, h-3).

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
1.	students working singly	T or PP's may be pres to render assist &/or super-vision as req		printed & written mat'l	reading	undifferen-tiated teach-ing space	desk	20 SF	68°	L	2	
2.	"	"		"	"	"	carrel	20 SF	68°	L	2	30 FC at carrel
3.	"	"		"	"	"	random	20 SF	68°	L	2	
4.	"	"		pencil, pen, paper	writing	"	desk	20 SF	68°	L	2	
5.	"	"		"	"	"	carrel	20 SF	68°	L	2	30 FC at carrel
6.	"	"		"	"	"	random	20 SF	68°	L	2	
7.	"	"		chalk board fixed	"	"	fixed, vertical surface	20 SF	68°	L	2	50 FC at chalkboard
8.	"	"		chalk board movable	"	"	random	20 SF	68°	L	2	50 FC at chalkboard
9.	"	"		vertical display surface, fixed	reading	"	fixed, vertical surface	20 SF	68°	L	2	50 FC at display
10.	"	"		vert display surface, movable	"	"	random	20 SF	68°	L	2	50 FC at display
11.	"	"		pre-recorded playback mach	listening	"	"	20 SF	68°	L	2	
12.	"	"		"	listening & writing	"	desk	20 SF	68°	L	2	

FIGURE 1/1

	EDUCATIONAL TASKS						DESIRABLE ENVIRONMENTAL CONDITIONS					
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
13.	students working singly	T or PP's may be pres to render assist &/or supervision as req		pre-recorded playback mach	listening & writing	undifferentiated teaching space	carrel	20 SF	68°	L	2	30 FC at carrel
14.	"	"		"	"	"	random	20 SF	68°	L	2	
15.	"	"		record-playback machine	recording & listening	"	random	20 SF	68°	L	2	
16.	"	"		"	reading recording listening	"	desk	20 SF	68°	L	2	
17.	"	"		"	"	"	carrel	20 SF	68°	L	2	30 FC at carrel
18.	"	"		"	"	"	random	20 SF	68°	L	2	
19.	"	"		front projector	viewing	"	random	20 SF	68°	L	2	
20.	"	"		"	viewing writing & poss read'g	"	desk	20 SF	68°	L	2	
21.	"	"		"	"	"	carrel	20 SF	68°	L	2	30 FC at carrel
22.	"	"		"	"	"	random	20 SF	68°	L	2	
23.	"	"		self-contained image-reprod'g unit with or without sound	viewing & poss. listening	"	random	20 SF	68°	L	1	

FIGURE i/2

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
24.	students working singly	T or PP's may be pres to render asst or supervision as required		self-contained image reprod'g unit with or without sound	viewing & listening writing reading keyb'd op'n	undifferentiated teaching space	desk	20 SF	68°	L	2	
25.		"		"	"	"	carrel	20 SF	68°	L	1	30 FC at carrel
26.	"	"		"	"	"	random	20 SF	68°	L	1	
27.	"	"		image reprod'g terminal with or without sound	viewing listening	"	near terminal	20 SF	68°	L	1	
28.	"	"		"	viewing listening writing reading key b'd op'n	"	desk near terminal	20 SF	68°	L	1	Light level 2 when required for reading and writing
29.	"	"		"	"	"	carrel	20 SF	68°	L	1	30 FC at carrel
30.	"	"		"	"	"	random	20 SF	68°	L	1	30 FC when required
31.	"	"		misc. equip. req. no services ex't electricity	operating equipment	"	"	20 SF	68°	L	1	30 FC for operating equipment
32.	"	"		art supplies work surfaces	drawing painting	"	random	20 SF	68°	L	3	
33.	"	"		supplies as required	construc'n or op'n	"	desk or worktable	20 SF	68°	L	2	
34.	smaller than class size	"		none	discussion	"	random	20 SF	68°	L	1	
35.	"	"		none	one student recites with or without notes	"	random	20 SF	68°	L	2	

FIGURE 1/3

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
36.	smaller than class size	T or PP's may be pres to render asst or supervision as required		printed or written matter	one student recites or reads	undifferentiated teaching space	random	20 SF	68°	L	2	
37.	"	"		paper & pencil	discussion w writing	"	desk or table	20 SF	68°	L	2	
38.	"	"		chalk board fixed	discussion w writing	"	fixed, vert. surface	20 SF	68°	L	2	50 FC at chalkboard
39.	"	"		chalk board movable	"	"	random	20 SF	68°	L	2	50 FC at chalkboard
40.	"	"		vert. display surface fixed	reading discussion	undifferentiated teaching space	fixed, vert surface	20 SF	68°	L	2	50 FC at display
41.	"	"		vert. display surface	"	"	random	20 SF	68°	L	2	50 FC at display
42.	"	"		supplies as required	construction operation	"	desks or worktable	20 SF	68°	L	2	Additional FC as req'd
43.	"	"		art supplies work surface	drawing & painting	"	random	20 SF	68°	L	3	
44.	"	"		pre-recorded playback mach.	listening discussion	"	random	20 SF	68°	L	2	
45.	"	"		"	listening writing discussion	"	table	20 SF	68°	L	2	
46.	"	"		record play-back machine	recording listening discussion	"	table	20 SF	68°	L	2	
47.	"	"		front projector	viewing listening discussion	"	random	20 SF	68°	L	2	
48.	"	"		" "	viewing discussion writing poss. reading	"	table	20 SF	68°	L	1	Light level 2 when required for writing, reading

FIGURE 1/4

No.	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
49.	smaller than class size	T or P P's may be pres to render asst or supervision as required		self-contained image reprod'g unit with or without sound	viewing listening discussion	undifferentiated teaching space	table	20 SF	68°	L	2	
50.	"	"		written or printed mat'l props	rehearsal for group presentation	"	random	20 SF	68°	L	2	Additional FC when required
51.	"	"		material as needed	one person gives demonstration to group	"	random	20 SF	68°	L	2	50 FC at demonstration area
52.	class size	"		None	discussion	"	class & teacher in fixed positions	20 SF	68°	L	2	
53.	"	"		"	"	"	class fixed; teacher moving freely	20 SF	68°	L	2	
54.	"	"		vert display surface; chalk board fixed	discussion with display	"	class fixed T'r at fixed vert displ surface	20 SF	68°	L	2	50 FC at display and chalkboard
55.	"	"		movable display	discussion with demonstration or display	"	class fixed; T at movable display	20 SF	68°	L	2	50 FC at display
56.	"	"		paper and pencil	discussion writing	"	class & T in fixed positions at desks	20 SF	68°	L	2	

FIGURE i/5

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
57.	class size	T or PP's may be pres to render asst or supervision as required		paper & pencil	discussion & writing	undifferentiated teaching space	class fixed; T moving freely, class at desks	20 SF	68°	L	2	
58.	"	"		vert display surface chalk board fixed paper & pencil	discussion with displ. writing	"	class fixed T. at fixed vert displ surface class at desks	20 SF	68°	L	2	50 FC at display and chalkboard
59.	"	"		movable displ paper & pencil	discussion with demonstration or display writing	"	class fixed; T. at movabl. display; class at desks	20 SF	68°	L	2	50 FC at display
60.	"	"		misc. equip't req'g no services except elec.	operating equipment	"	random	20 SF	68°	L	2	50 FC for operating equipment
61.	"	"		prerecorded playback mach	listening	"	"	20 SF	68°	L	2	
62.	"	"		"	listening & writing	"	"	20 SF	68°	L	2	30 FC when required for writing
63.	"	"		"	"	"	desk	20 SF	68°	L	2	30 FC when required for writing
64.	"	"		front projector	viewing	"	random	20 SF	68°	L	1	
65.	"	"		" "	viewing writing & poss read'g	"	"	20 SF	68°	L	1	30 FC when required
66.	"	"		" "	"	"	desk	20 SF	68°	L	1	30 FC when required

FIGURE i/6

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
67.	class size	T & PP's may be present to render assist. &/or super-vision as req.		image reprod'g terminal of sufficient size for class view'g with or without sound	viewing listening	undifferen-tiated teaching space	random	20 SF	68°	L	1	
68.	"	"		"	viewing listening writing	"	"	20 SF	68°	L	1	Light level 2 when required
69.	"	"		"	"	"	desk	20 SF	68°	L	1	Light Level 2 when required
70.	"	"		art supplies	drawing coloring	"	desk or table	20 SF	68°	L	3	
71.	student working singly	"		printed written mat'l	reading looking	art room	random	25 SF	68°	L	2	
72.	"	"		"	"	"	desk or table	20 SF	68°	L	2	
73.	"	"		paper, pencil pen	drawing	"	desk	20 SF	68°	L	3	supplementary lighting as necessary
74.	"	"		paper canvas paint etc	painting	"	desk table easle	20 SF	68°	L	3	supplementary lighting as necessary
75.	"	"		Paper, pencil	mechanicals paste-ups etc.	"	desk or table	20 SF	68°	L	3	60-100 FC at desk or table
76.	"	"		clay, stone etc	sculpture	"	table pedestal	20 SF	68°	L	3	supplementary light as necessary; north light preferred
77.	"	"		small movable	arts & crafts	"	random	20 SF	68°	L	3	"
78.	"	"		large fixed	"	"	at equip't	20 SF	68°	L	3	"
79.	"	"			clean-up	"		20 SF	68°	L	2	

FIGURE 1/7

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
80.	class-sized group	T. or PP's may be present to render assist. &/or super-vision as req.		printed written mat'l	reading looking	art room	random	25 SF	68°	L	3	supplementary light as necessary
81.	"	"		"	"	"	desk or table	20 SF	68°	L	3	supplementary light as necessary
82.	"	"		paper, pencil pen	drawing	"	desk	20 SF	68°	L	3	supplementary light as necessary
83.	"	"		paper, canvas paint, etc.	painting	"	desk table easle	20 SF	68°	L	3	supplementary light as necessary
84.	"	"			mechanicals paste-ups etc.	"	desk or table	20 SF	68°	L	3	60-100 FC at desk or table
85.	"	"		clay, stone etc	sculpture	"	table pedestal	20 SF	68°	L	3	suppl. light as nec.; north light pref.
86.	"	"		small movable	arts & crafts	"	random	20 SF	68°	L	3	"
87.	"	"		large fixed	"		at equip't	20 SF	68°	L	3	"
88.	"	"			clean-up	"		20 SF	68°	L	3	
89.	"	"		none	discussion	"		20 SF	68°	L	2	
90.	"	"		vert display surface	"	"	fixed, vert surface	20 SF	68°	L	2	50 FC at display
91.	"	"		free-standing display	"	"	random	20 SF	68°	L	2	50 FC at display

FIGURE i/8

EDUCATIONAL TASKS								DESIRABLE ENVIRONMENTAL CONDITIONS					
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
92.	students working singly	T or PP's may be present to render assist &/or supervision as req		elect equip calculators computers	oper'n of equipment	shops & spec teach'g spaces	fixed student station	± 30 SF (variable as per equipment)	68°	L	2	supplementary lighting as required at equipment
93.	"	"		tape recorders earphones phonograph	"	"	"	"	68°	L	2	"
94.	"	"		b'k keeping machine stenotype typewriter				"	68°	L	2	"
95.	"	"		kiln potter's wheel	"	"	"	"	68°	H	2	"
96.	"	"		add'g machine cash register	"	"	"	"	68°	L	2	"
97.	"	"		range, mixer sewing machine elect. iron	"	"	"	"	68°	H	2	60-100 FC at sewing machines
98.	"	"		lathe, drill	"	"	"	"	68°	H	2	100 FC at lathe, drill
99.	"	"		auto quip't	"	"	"	"	68°	H	2	60 FC at auto equip.
100.	"	"		print'g equip't	"	"	"	"	68°	H	2	60-100 FC at printing equipment
101.	"	"		draft'g equip't	"	"	"	"	68°	L	2	60-100 FC at drafting equipment
102.	"	"		elect. shop equipment	"	"	"	"	68°	L	2	60-100 FC at electric shop equipment
103.	"	"		same as 92 - 102	reading	"	"	"	68°	L-H	2	(same as 92-102)
104.	"	"		"	writing	"	"	"	68°	L-H	2	(")
105.	"	"		"	listening	"	"	"	68°	L-H	2	(")
106.	"	"		"	observing	"	"	"	68°	L-H	2	(")

FIGURE i/9

	EDUCATIONAL TASKS						DESIRABLE ENVIRONMENTAL CONDITIONS					
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
107.	students working singly	T. or PP's may be present to render assist &/or super-vision as req.		chalkboard vert display (fixed,movable)	reading	shops & specialized teaching spaces	random	± 30 SF	68°	L-H	2	50 FC at display and chalkboard
108.	"	"		"	writing	"	"	"	68°	L-H	2	"
109.	"	"		books manuals operat'g instr	reading	"	"	"	68°	L-H	2	
110.	"	"		"	writing	"	fixed	"	68°	L-H	2	
111.	small group, less than class size	"		none	discussion	"	random	"	68°	L-H	2	
112.	"	"		equipment as # 52 - # 102	demonstrat'n by one person	"	fixed	"	68°	L-H	2	suppl. light as req. at equipment
113.	"	"		"	individual & group familiariza-tion	"	"	"	68°	L-H	2	"
114.	"	"		audio-visual	demonstration & discussion	"	random	"	68°	L-H	2	
115.	"	"		appropriate materials	"	"	fixed	"	68°	L-H	2	
116.	class sized group	"		as needed	discussion	"	fixed	"	68°	L-H	2	
117.	"			class equip't	operation of equip't	"	"	"	68°	L-H	2	suppl. light as req. at equipment
118.	"	"		" "	demonstrat.'n & observ'n (equipment)	"	"	"	68°	L-H	2	"

FIGURE i/10

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
119.	class sized group	T. or PP's may be present to render assist &/or supervision as req.		class equip't	demonstration & discussion (materials)	shops & special teaching spaces	fixed student station	30 SF	68°	L-H	2	50 FC at equipment
120.	individuals, one or more	unsupervised				toilet	at equip't	10 SF	68°	H	2	
121.	various sized groups	as needed	as needed	sound system	listening	auditorium	random	6-10 SF	68°	I	2	
122.	"	"	"	written, printed, photo mat'l in possession of each person	reading	"	"	6-10 SF	68°	I	2	
123.	"	"		projected material	reading listening	"	"	6-10 SF	68°	I	1	
124.	"	"	"	display material	"	"	"	6-10 SF	68°	I	2	50 FC at display
125.	"	"	"	as needed	listening; looking at stage-located activity	"	"	6-10 SF	68°	I	1	
126.	"	"	"	" "	discussion	"	"	6-10 SF	68°	I	1	
127.	"	"	"	" "	make-up dressing for stage act'y	"	dressing rooms	6-10 SF	68°	I	1	make-up lights at mirrors
128.	"	"	"	" "	discussion; independent for each group	"	random	6-10 SF	68°	I	1	
129.	"	"	"	" "	performing in stage act'y	"	stage	6-10 SF	68°	I	1	theatrical lighting as required

FIGURE i/11

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
130.	class sized group	T. or PP's may be present to render assist &/or supervision as req.	as needed	as needed	operation of proj. equip.	auditorium		6-10 SF	68°	1	1	Additional FC as required at equipment
131.	"	"	"	"	control of light, sound for stage act'y		projection booth	6-10 SF	68°	I	1	Additional FC as required at equipment
132.	from random individuals to entire school	"	all other personnel		walking	circulation	random		68°	L	1	
133.	"	"	"		talking	"	"		68°	L	1	
134.	"	"	"		socializing	"	"		68°	L	1	
135.	"	"	"	displays	reading	"	"		68°	L	1	30 FC at displays
136.	"	"	"	bulletin boards	"	"	"		68°	L	1	30 FC at bulletin boards
137.	"	"	"	as needed	transporting school supplies	"	"		68°	L	1	
138.	"	"	"	"	informal reading				68°	L	1	
139.	"	"	"	"	entry egress, all spaces				68°	L	2	
140.	"	"	"	fountains	drinking				68°	L	1	
141.	"	"	"	"	discussion				68°	L	1	

FIGURE i/12

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
142.	large nc's of singles and small groups	supervisors as needed	lunch room personnel food prep & serving		eating socializing reading discussion	cafeteria	random	12 SF	65°	I	1	Light level 2 when used as Study Hall
143.	various sized groups, school & community			none	talking listening discussing	"	"	12 SF	65°	I	1	
144.	various - sized groups			as needed	ping pong	game room	"	1[illegible] SF	65°	I	2	
145.	class sized groups	teacher		"		class room	"	20 SF	65°	L	2	
146.	none	none	lunch room personnel	freezers, ranges, heating units	food prep. serv'g sinks clean-up utensils	kitchen	"		65°	I-H	3	
147.	single class group	T. & PP's may be present to render assist &/or super - vision as req.	organic personnel	recorded mat'l player	listening	library (multi-media center)	"	25 SF	68°	L	1	
148.	"	"	"		reading	"	"	25 SF	68°	L	2	
149.	"	"	"		observing	"	"	25 SF	68°	L	1	
150.	"	"	"		writing	"	"	25 SF	68°	L	2	
151.	"	"	"		browsing	"	"	25 SF	68°	L	2	
152.	"	"	"	as needed	equipment operation	"	"	25 SF	68°	L	1	Suppl. light as required

FIGURE i/13

	EDUCATIONAL TASKS						DESIRABLE ENVIRONMENTAL CONDITIONS					
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
153.	single class group	T. & PP"s may be present to render assist &/or super - vision as req.	organic personnel	as needed	construction and/or oper'n (indiv. projects)	library (multi-media center)	random	25 SF	68°	L	2	Supplementary light as required
154.	"	"	"	"	listening (various modes)	"	"	25 SF	68°	L	1	
155.	"	"	"	"	reading	"	"	25 SF	68°	L	2	
156.	"	"	"	"	observing	"	"	25 SF	68°	L	1	
157.	"	"	"	"	writing	"	"	25 SF	68°	L	2	
158.	"	"	"	"	browsing	"	"	25 SF	68°	L	2	
159.	"	"	"	"	equipment operation	"	"	25 SF	68°	L	1	Suppl. light as required
160.	"	"	"	as and if needed	discussion	"	"	25 SF	68°	L	1	
161.	"		"	"	construction &/or oper'n (group projects)	"	"	25 SF	68°	L	2	Suppl. light as required
162.	class-sized groups	"	organic personnel as needed	"	listening	"	"	25 SF	68°	L	1	
163.	"	"	"	"	reading	"	"	25 SF	68°	L	2	
164.	"	"	"	"	observing	"	"	25 SF	68°	L	1	
165.	"	"	"	"	writing	"	"	25 SF	68°	L	2	
166.	"	"	"	"	discussion	"	"	25 SF	68°	L	1	

FIGURE i/14

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
167.	students working singly	T or PP's may be present to render assist &/or supervision as req.		written printed mat'l	reading	library (multi-media center)	random	25 SF	68°	L	2	
168.	"	"		"	"	"	desk	25 SF	68°	L	2	
169.	"	"		"	"	"	carrel	25 SF	68°	L	2	50 FC at carrel
170.	"	"		pencil, pen, Paper	writing	"	random	25 SF	68°	L	2	
171.	"	"		"	"	"	desk	25 SF	68°	L	2	
172.	"	"		"	"	"	carrel	25 SF	68°	L	2	50 FC at carrel
173.	"	"		chalk board fixed	"	"	random	25 SF	68°	L	2	50 FC at chalkboard
174.	"	"		chalk board movable	"	"	random	25 SF	68°	L	2	50 FC at chalkboard
175.	"	"		vert display surface fixed	reading	"	random	25 SF	68°	L	2	50 FC at display
176.	"	"		vert display surface movable	"	"	random	25 SF	68°	L	2	50 FC at display
177.	"	"		pre-recorded playback mach	listening	"	random	25 SF	68°	L	1	
178.	"	"		"	listening & writing	"	random	25 SF	68°	L	2	
179.	"	"		"	"	"	desk	25 SF	68°	L	2	30 FC at desk
180.	"	"		"	"	"	carrel	25 SF	68°	L	2	30 FC at carrel
181.	"	"		record-playback machine	recording & listening	"	random	25 SF	68°	L	1	

FIGURE 1/15

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
182.	students working singly	T or PP's may be present to render assist &/or supervision as req.		record-play-back machine	reading recording & listening	library (multi-media center)	random	25 SF	68°	L	2	
183.	"	"		"	"	"	desk	25 SF	68°	L	2	30 FC at desk
184.	"	"		"	"	"	carrel	25 SF	68°	L	2	30 FC at carrel
185.	"	"		front projector	viewing	"	random	25 SF	68°	L	1	
186.	"	"		"	viewing & writing & poss reading	"	random	25 SF	68°	L	2	
187.	"	"		"	"	"	desk	25 SF	68°	L	2	30 FC at desk
188.	"	"		"	"	"	random	25 SF	68°	L	2	
189.	"	"		self-contained image re-produc'g unit with or with-out sound	viewing & possible listening	"	"	25 SF	68°	L	1	
190.	"	"		"	viewing & listening writing reading keyboard operating	"	desk	25 SF	68°	L	2	30 FC at desk
191.	"	"		"	"	"	carrel	25 SF	68°	L	2	30 FC at carrel
192.	"	"		"	"	"	random	25 SF	68°	L	2	
193.	"	"		image re-produc'g terminal with or without sound	viewing listening	"	random	25 SF	68°	L	1	

FIGURE i/16

No.	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
194.	students working singly	T or PP's may be present to render assist &/or super-vision as req		image re-produc'g terminal with or without sound	viewing listening writing reading keyb'd op'n	library (multi-media center)	desk	25 SF	68°	L	2	Light level 2 for reading, writing
195.	"	"		"	"	"	carrel	25 SF	68°	L	2	"
196.	"	"		"	"	"	random	25 SF	68°	L	2	"
197.	"	"		misc. equip't req. no services except elect.	operating equipment	"	"	25 SF	68°	L	1	Additional light as required for equipment
198.	"	"		art supplies work surfaces	drawing painting	"	random	25 SF	68°	L	3	
199.	"	"		supplies as required	construction or operation	"	desk or worktable	25 SF	68°	L	2	50 FC at desk or worktable
200.	smaller than class size	"		none	discussion	"	random	25 SF	68°	L	1	
201.	"	"		"	one student recites with or without notes	"	random	25 SF	68°	L	1	30 FC at recitation station
202.	"	"		printed or written matter	one student recites or reads	"	"	25 SF	68°	L	1	30 FC at recitation station
203.	"	"		paper & pencil	discussion with writing	"	desk or table	25 SF	68°	L	2	
204.	"	"		chalk board fixed	discussion with writing	"	fixed vert surface	25 SF	68°	L	2	50 FC at chalkboard
205.	"	"		chalk board movable	"	"	random	25 SF	68°	L	2	50 FC at chalkboard

FIGURE i/17

	EDUCATIONAL TASKS						DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
206.	smaller than class size	T or PP's may be present to render assis &/or super-vision as req		vert display surface fixed	reading discussion	library (multi-media center)	fixed vert surface	25 SF	68°	L	2	50 FC at display
207.	"	"		vert display surface movable	reading discussion	"	random	25 SF	68°	L	2	50 FC at display
208.	"	"		supplies as required	construction and/or operation	"	desks or worktable	25 SF	68°	L	2	50 FC at desks or worktables
209.	"	"		art supplies work surface	Drawing & painting	"	random	25 SF	68°	L	3	
210.	"	"		pre-recorded playback mach	listening discussion	"	"	25 SF	68°	L	1	
211.	"	"		"	listening writing discussion	"	table	25 SF	68°	L	2	
212.	"	"		record - play-back machine	recording listening discussion	"	"	25 SF	68°	L	1	
213.	"	"		front projector	"	"	random	25 SF	68°	L	1	
214.	"	"		"	viewing writing discussion poss. reading	"	table	25 SF	68°	L	2	30 FC if necessary
215.	"	"		self contained image reprod'g unit with or without sound	viewing listening discussion	"		25 SF	68°	L	1	
216.	"	"		written or printed mat'l props	rehearsal for group presentation	"	random	25 SF	68°	L	2	

FIGURE 1/18

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
217.	smaller than class size	T or PP's may be present to render assist &/or super-vision as req		material as needed	one person gives demon-stration to rest of group	library (multi-media center)	random	25 SF	68°	L	1	50 FC at demonstration station
218.	class size	"		none	discussion	"	class & T'r in fixed positions	25 SF	68°	L	1	
219.	"	"		"	"	"	class fixed. teacher moving freely	25 SF	68°	L	1	
220.	"	"		vert display surface chalkb'd fixed	discussion with display	"	class fixed T.at fixed display surface	25 SF	68°	L	1	50 FC at demonstration station
221.	"	"		movable display	discussion with demon-stration or display	"	class fixed. T.at movable display	25 SF	68°	L	1	50 FC at demonstration station
222.	"	"		paper & pencil	discussion & writing	"	class & T.in fixed pos at desks	25 SF	68°	L	2	
223.	"	"		"	"	"	class fixed. T.moving freely	25 SF	68°	L	2	
224.	"	"		vert. display surface chalkb'd fixed paper & pencil	discussion with display writing	"	class fixed. T.at fixed vert display surface, class at desks	25 SF	68°	L	2	50 FC at display
225.	"	"		movable displ. paper & pencil	discussion with demon-stration or display; writing	"	class fixed, T.at movable display; class at desks	25 SF	68°	L	2	50 FC at display

FIGURE i/19

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	STUDENT STATION	SQ FT AREA PER STUDENT	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
226.	class sized group	T or PP's may be present to render assist &/or super-vision as req		misc. equip't req. no services except elect.	operating equipment	library (multi-media center)	random	25 SF	68°	L	2	Additional light at equipment as necessary
227.	"	"		pre-recorded playback mach	listening	"	random	25 SF	66°	L	1	
228.	"	"		"	listening & writing	"	"	25 SF	68°	L	1	Light level 2 if necessary
229.	"	"		"	"	"	desk	25 SF	68°	L	1	30 FC at desk
230.		"	as needed		running	gymnasium	random	15 SF	60°	H	1	
231.	"	"	"	"	walking	"	"	15 SF	60°	H	1	
232.	"	"	"		formal class exercises	"	"	15 SF	60°	H	2	
233.	"	"	"	as needed	participat'g in games	"	"	15 SF	60°	H	2	Additional light as necessary
234.	"	"	"	horizontal bars, ropes, trampolines weight mach., bar bells	using gym equipment	"	"	15 SF	60°	H	2	Additional light as necessary
235.	"		"		shower	"	shower room	12 SF	68°	H	1	
236.	"		"		put on uniform, street clothes	"	locker room	12 SF	68°	H	1	

FIGURE i/20

	EDUCATIONAL TASKS							DESIRABLE ENVIRONMENTAL CONDITIONS				
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	WORK STATION	SQ FT AREA PER PERSON	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
237.	one st'd or small group	administrator		none	discussion	office	random	100 SF	68°	L	1	30 FC at desks
238.	none	"	secre-taries, clerks, etc.	mimeograph or xerox, typewriter	admin. work reading talking writing typing	"	"	100 SF	68°	L	2	30 FC at workstation
239.	one st'd or small group	teacher-guidance		none	discussion	"	random	100 SF	68°	L	1	30 FC at desk
240.	none	administrator	teaching personnel, one or small group	"	"	"	random	100 SF	68°	L	1	30 FC at desk
241.	"	"	none	dictaphone	recording	"	equipment	100 SF	68°	L	1	30 FC at workstation
242.	"	"		P.A. system	talking	"	at equip't	100 SF	68°	L	2	Additional light as required
243.	small group	none	none	typewriter pen, paper, rexograph	writing, discussion, reading	office for student publication	"	100 SF	68°	L	2	Additional light as required
244.	variable	as needed	as needed	as needed	discussion	conference	random	100 SF	68°	L	2	Additional light as required
245.		"	"	"	placing addit'l items in storage, arrang'g, removing items from storage	storage	random	100 SF	60°	I	1	Additional light as required
246.	none	none	as needed	boilers pumps, fans, compressors, gauges, controls	operating heating/ cooling ventilating and related equipment	unfinished space	boiler room	100 SF	60°	H	1	Additional light as required at equipment

FIGURE i/21

	EDUCATIONAL TASKS						DESIRABLE ENVIRONMENTAL CONDITIONS					
	STUDENT GROUPING	TEACHERS & PARA-PROF	OTHER PERSONNEL	TEACHING AIDS & EQUIPMENT	EDUC. OR OTHER ACT'Y	SPACE DESIGNATION	WORK STATION	SQ FT AREA PER PERSON	TEMP F	VENT LEVEL	AMBIENT LIGHT LEVEL	TASK LIGHT
247.	none	none	as needed	fans controls	operating fans and heating/ cooling coils	fan room (s)	at equipment		60°	H	1	Additional light as required at equipment
248.	"	"	"	as needed	accumulate and constrict refuse prior to disposal	refuse room	at equipment		60°	H	1	Additional light as required at equipment
249.	"	"	"	hand and machine tools	repair of various items of equipment	work room	workbench		65°	H	2	Additional light as required at equipment
250.	"	"	"	tools as needed	maintenance and repair of elevator equipment	elevator equipment room	workbench		65°	H	2	Additional light as required at equipment
251.	"	"	"	incinerator	burning rubbish	incinerator	at incinerator		60°	H	1	Additional light as required at equipment

FIGURE i/22